

The

**HOW  
AND  
WHY**

*Wonder Book of*

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# AIR AND WATER









THE HOW AND WHY WONDER BOOK OF  
**AIR AND WATER**

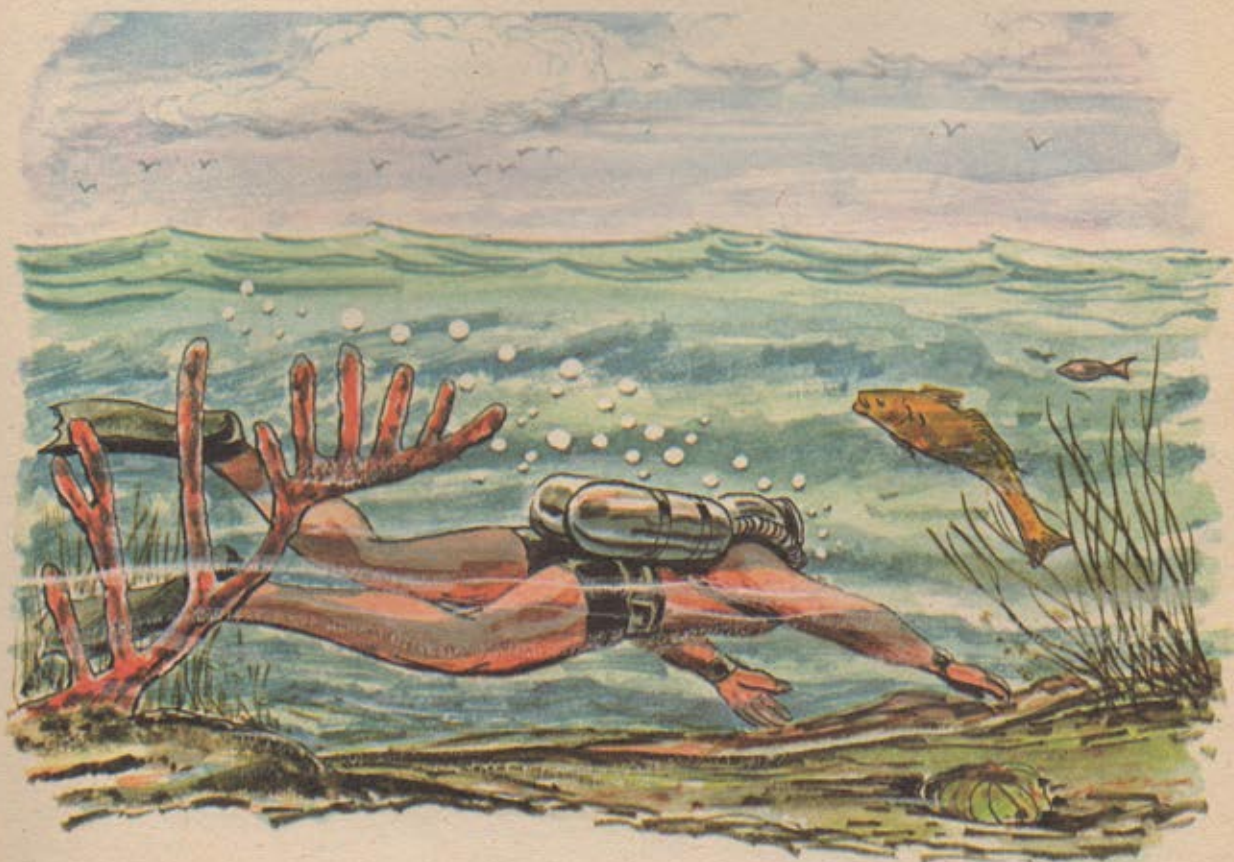
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## Introduction

I like to think of air and water as bridges, for across them move the aeroplanes and ships that bring closer together the world's people. But air and water are bridges in another sense. What scientists have learned about many of the physical characteristics of these *fluids*, they have been able to use as bridges to understanding other *fluids* — gases and liquids.

With this *How and Why Wonder Book of Air and Water* you can cross these bridges of discovery with the scientists. You will see just how many of the big ideas about air and water are true of other gases and liquids. Perhaps, as you study, you will cross another bridge, the one that will bring to you a greater appreciation of air and water. Though they are all around you, you may never have noticed how surprising and interesting these substances are.

Because you may want to be the scientist and cross that first bridge yourself, this book suggests experiments for you to try. So read and think, experiment, observe, and check your findings. Have a good passage as you cross new bridges with *The How and Why Wonder Book of Air and Water*.

*Paul E. Blackwood*

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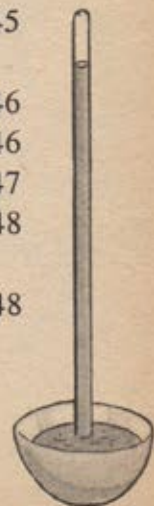
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## Characteristics of Air and Water

Air and water are familiar to all of us. The earth we live on is surrounded by a great ocean of air called the atmosphere. Three quarters of the earth's surface is covered by the waters of oceans, lakes, rivers, and streams.

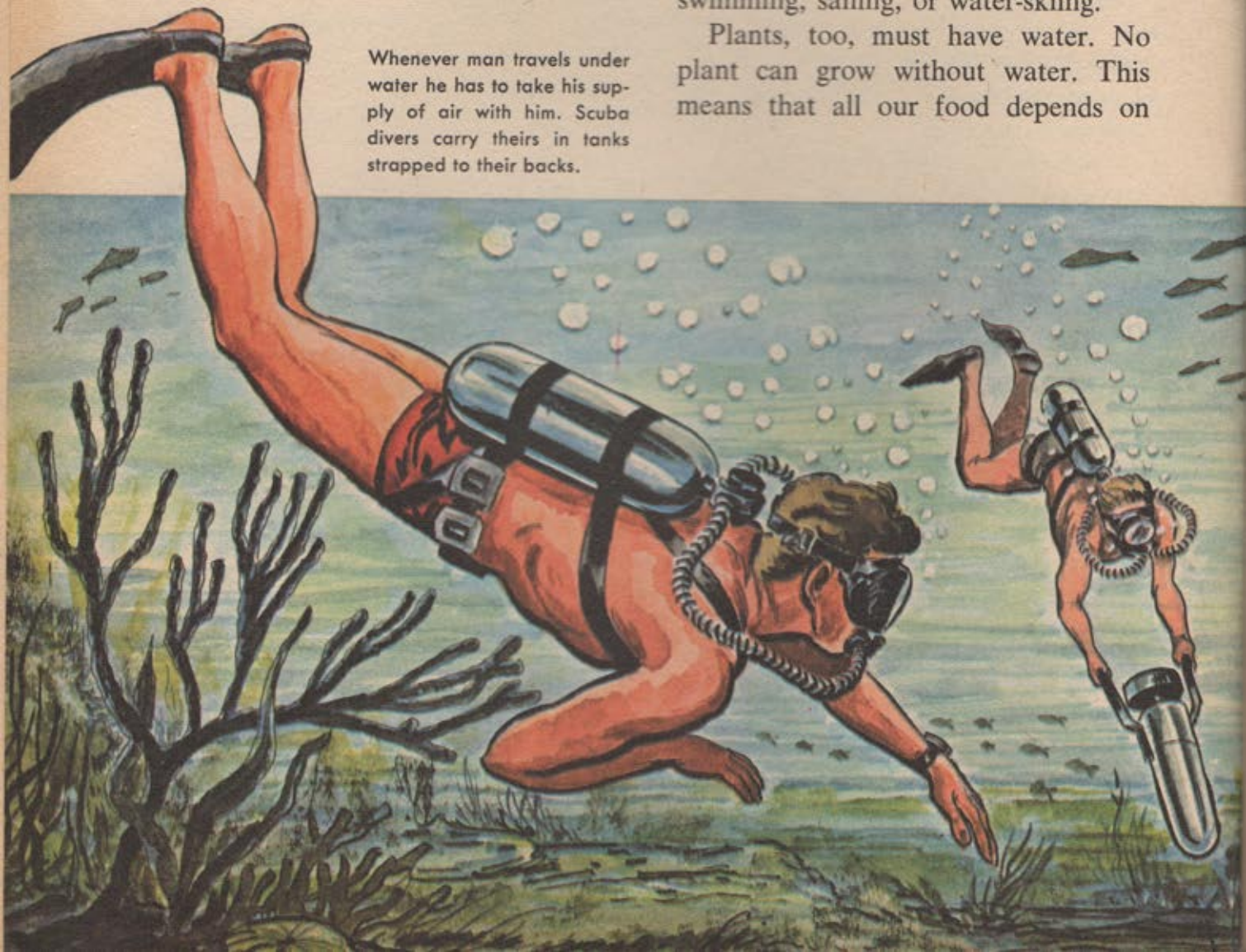
Air fills all the open hollows on the surface of the earth. The air surrounding us is necessary for life. All animals breathe air, and if deprived of it, they die. Because air surrounds our bodies all the time, we usually are not aware of how important it is. But whenever man travels into space or under water, he realizes air's importance because he must take a supply of it with him.

Next to air, water is probably the substance most important to us. All living things contain water. More than two thirds of your body is made up of water. The water in your body helps dissolve the food you eat, which is then carried in the blood to your living cells. Water also helps carry away the dissolved waste materials from the cells. And water helps to keep your body at the right temperature.

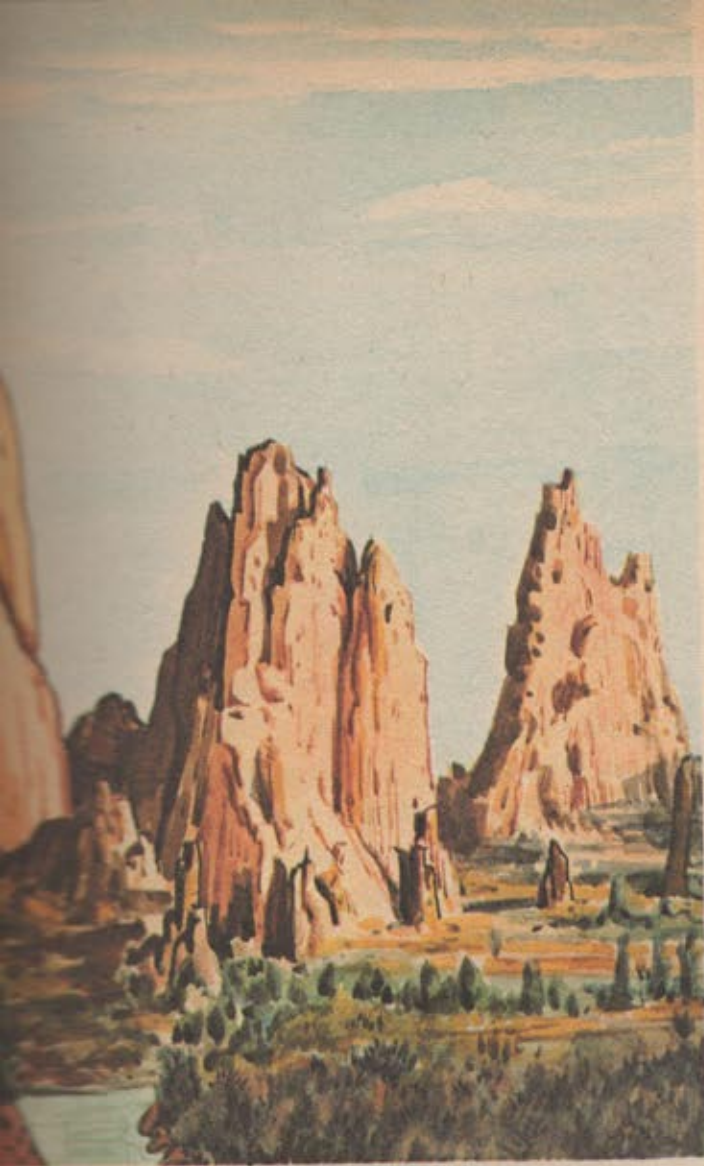
Water is important not only inside your body, but in your daily life as well. It is used for cooking, bathing, washing clothes and dishes, and cleaning. And water provides recreation such as swimming, sailing, or water-skiing.

Plants, too, must have water. No plant can grow without water. This means that all our food depends on

Whenever man travels under water he has to take his supply of air with him. Scuba divers carry theirs in tanks strapped to their backs.







Solid rock is carved into beautiful and strange shapes when sand, carried by the force of the wind, scrapes against it. The rock spires in Colorado's Garden of the Gods are examples of such formations.

water because all food — even meat, which is the flesh of plant-eating animals — comes from plants.

Water is an important source of power. Man uses the force of running water to turn the wheels of mills and to make electricity.

Water shapes the surface of the earth. Time and again, the force of the running waters of streams and rivers has worn down whole mountain ranges until they became flat plains. And the pounding of ocean waves on the shores

has shaped the coastlines of all the continents.

Air, too, causes changes in the earth's surface. A strong wind may pick up particles of soil and move them long distances. When the wind quiets down, the particles of soil fall to earth. In this way, the wind moves portions of the earth's surface from place to place. About 200,000 square miles of the Mississippi River basin are covered with rich soil that was carried there by the wind.

Much of our weather is due to the amount of water in the air. Clouds, fog, dew, rain, snow, and sleet are forms of water in the air. Moving air causes most of the changes in weather. As wind blows warm or cold, damp or dry, the weather changes.

When playing outdoors, you feel the wind on your face. On a very windy day, you have to lean forward and push hard in order to walk against the wind. Wind is moving air, so it is moving air that you feel, and it is moving air against which you have to push so hard to walk on a windy day.

You can't see air, but you have often seen what moving air can do. It moves leaves on trees, and it blows pieces of paper along the ground. You know that in storms the wind blows trees over, and may even blow the roofs off houses. A strong wind blowing from the sea toward shore can push so much water before it that towns along the shore may be flooded. Because air can do all these things, we know that it must be a real material, like wood or paper.

Air is a kind of matter, the substance



things are made of. Matter is anything that takes up space and has weight. A stone is matter. You can see that a stone takes up space, and if you pick it up, you can feel that it has weight. A piece of iron, your hat, a ball, and a glass and the milk it contains all are examples of matter because they all take up space and have weight. Air, too, takes up space and has weight. That is why we say that air is a kind of matter.

Air is a mixture of several gases. These gases do not have any colour, odour, or taste. You know that this is cause you cannot see or smell or taste air.

**What is air made of?**

A little more than one fifth of the air is oxygen. This gas is very important to all living things. If plants or animals are deprived of oxygen, they die.

A little less than four fifths of the air is nitrogen. This gas is also important to living things. Nitrogen is a part of all living tissues. However, living things cannot use nitrogen directly from the air, as they do oxygen. Plants get nitrogen from bacteria in the soil, and animals get it by eating plants. Humans obtain their nitrogen supply from animals in the form of meat and fish and, more directly, from plants in fruits and vegetables.

The third important gas in the air is carbon dioxide. Although air contains very little carbon dioxide compared to oxygen and nitrogen, the carbon dioxide is very important. Plants are the only living things that can make their own food and they need carbon dioxide

to do this. Plants provide food for all other living things.

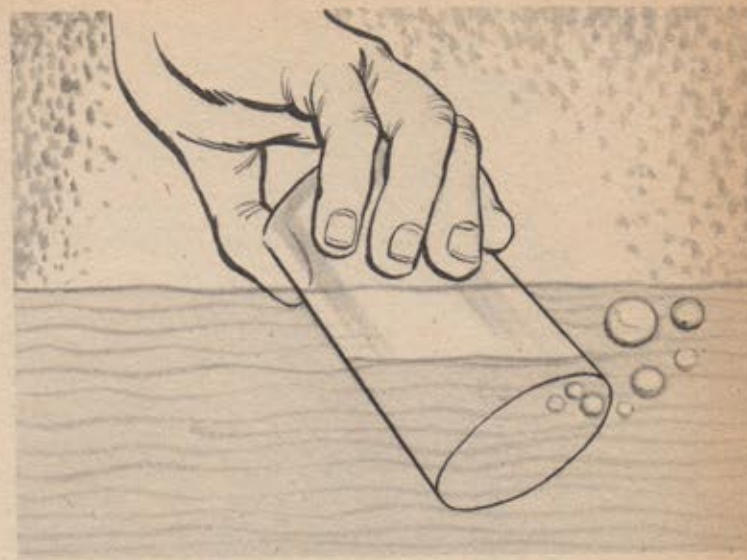
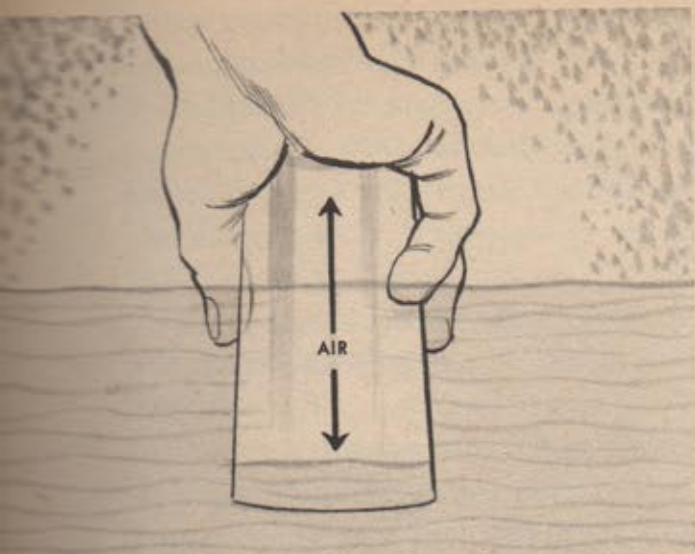
One part in every hundred parts of air is a mixture of half a dozen other gases. Two of these, helium and hydrogen, are very light gases. Because of their lightness, one use of these gases is for filling balloons; small toy ones and large weather balloons. The other four gases in air are neon, argon, krypton, and xenon. Neon gives the bright red-orange glow to the glass tubes of electric advertising signs. Argon in these glass tubes gives off a purple light, and krypton and xenon give off a blue light. Argon, along with nitrogen, is used to fill the electric light bulbs in your home. The argon makes the bulbs glow more brightly and last longer.

The proportions of the mixture of gases in the atmosphere are not always the same. If you could take apart a sample of air from near the ground and another one from a hundred miles above the earth, you would find that the amounts of the gases would be different in the two samples. The sample taken near the ground would have a higher proportion of the heavier gases: carbon dioxide, argon, krypton and xenon. The upper sample would have a higher proportion of hydrogen, helium, nitrogen, oxygen, and neon.

We have said that air is a kind of matter and that matter is something that takes up space. It may seem hard to believe that air takes up space, but you can easily show that this is true. All you need is

**How can you show that air takes up space?**





Air takes up space.

an ordinary drinking glass and a pail of water. The glass looks empty. If you were to show the glass to a friend and ask him what is in the glass, he would probably say, "Nothing," or, "It's empty." Put your hand in the glass. There seems to be nothing there; the glass certainly *feels* empty. But we have said that air fills all the hollow places on the surface of the earth. Surely, there must be air inside the glass.

Pour water into the glass until it is filled to the brim. The water that fills the glass has pushed all the air out of the glass. But suppose the air were trapped inside the glass and the water could not push it out. If air really takes up space, how can you fill the glass with water?

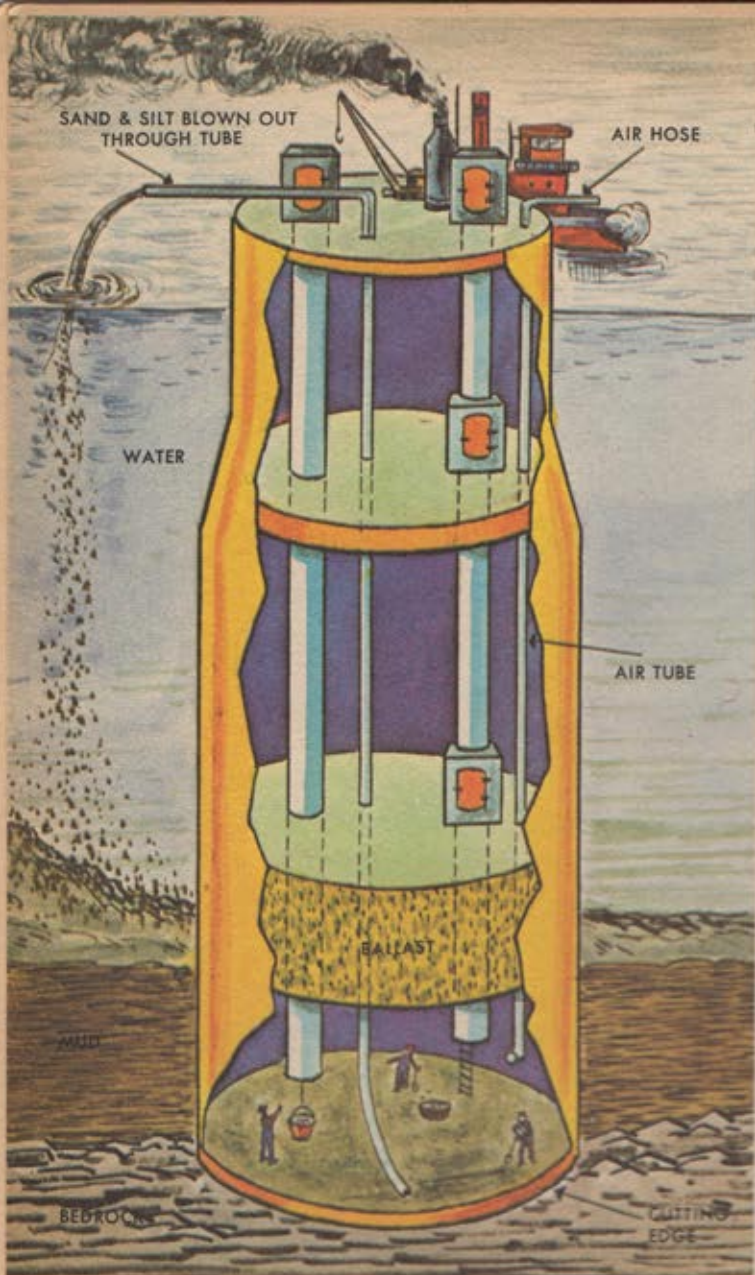
Pour all the water out of the glass. Now turn the glass upside down and push it down into the pail of water. Be sure you hold the glass perfectly straight. Do not tilt it to one side. Push the glass down into the water until all of it is under water. Now look closely. You

will see that only a small amount of water has risen into the glass. The rest of the glass is filled with air. The air is taking up the space inside the glass, and the water cannot fill it.

Now slowly tilt the glass to one side until some of the air escapes. You will see a large bubble of air rise to the surface of the water with a popping sound. Look at the glass again. This time, you will see that the water has risen higher in the glass. Now that the bubble of air is no longer taking up space in the glass, some water can get in. Each time you tip the glass and let air escape, more water will rise into it.

Using this same equipment, you can perform a trick to fool your friends. Bet them that you can put a handkerchief under water without getting it wet. Crumple the handkerchief and pack it firmly into the bottom of the glass. Now turn the glass upside down and lower it into the water as you did before. The handkerchief will stay dry as long as you hold the glass straight.





Very little water will enter the diving bell, or underwater caisson, because the air in it takes up space and prevents the water from rising. But if the men working at the bottom of the bell are to stay dry, no water at all should enter. To accomplish this compressed air is forced into the diving bell. Weighted in this way, it sinks. The workmen go in and out through airlocks which allow them gradually to get used to the high pressure.

The experiment you just performed with the glass and the pail of water showed you that water could not get into the glass as long as there was air inside it. This fact is used by men who

**What is a diving bell?**

must work under water. Perhaps the men must dig holes for the foundation of a bridge or a dam, or perhaps they must repair a sunken ship. They can do this and still remain dry by working inside a diving bell. A diving bell looks like a large iron bell. It is lowered beneath the water — open end down — until it rests on the bottom. Because the diving bell is filled with air, water does not rise into it, just as water did not rise into the glass. Air is taking up space inside the diving bell and water cannot take up the same space.

You remember that when you pushed the glass all the way down into the pail, a small amount of water did rise into the glass. If you had pushed the glass many feet under water, the water would have risen into it even further. To prevent water from rising into a diving bell, air is pumped into it from the surface.

The problem of showing that air has weight is a very old one. It was first solved in the second half of the sixteenth century by a young Italian scientist, Galileo Galilei.

**How can we prove that air has weight?**

It would be nice to repeat exactly what Galileo did, but we cannot because we need equipment especially made for this experiment. Instead, let us read what Galileo did, and we will learn the interesting way in which he proved that air has weight.

Galileo obtained a sturdy bottle with a narrow neck. Then he had a craftsman make a leather sack both airtight and watertight, and with a narrow neck. The sack was shaped pretty much like



the bottle but had only three quarters as much space inside.

Galileo filled the sack with water. He then wet the neck of the sack and slipped it over the neck of the bottle. The wet leather shrank and fitted so tightly around the neck of the bottle that not even air could move in or out of where the sack and bottle joined.

Squeezing and twisting the sack, Galileo forced water from the sack into the bottle. Then he wrapped the twisted empty sack around the neck of the bottle and tied it in place.

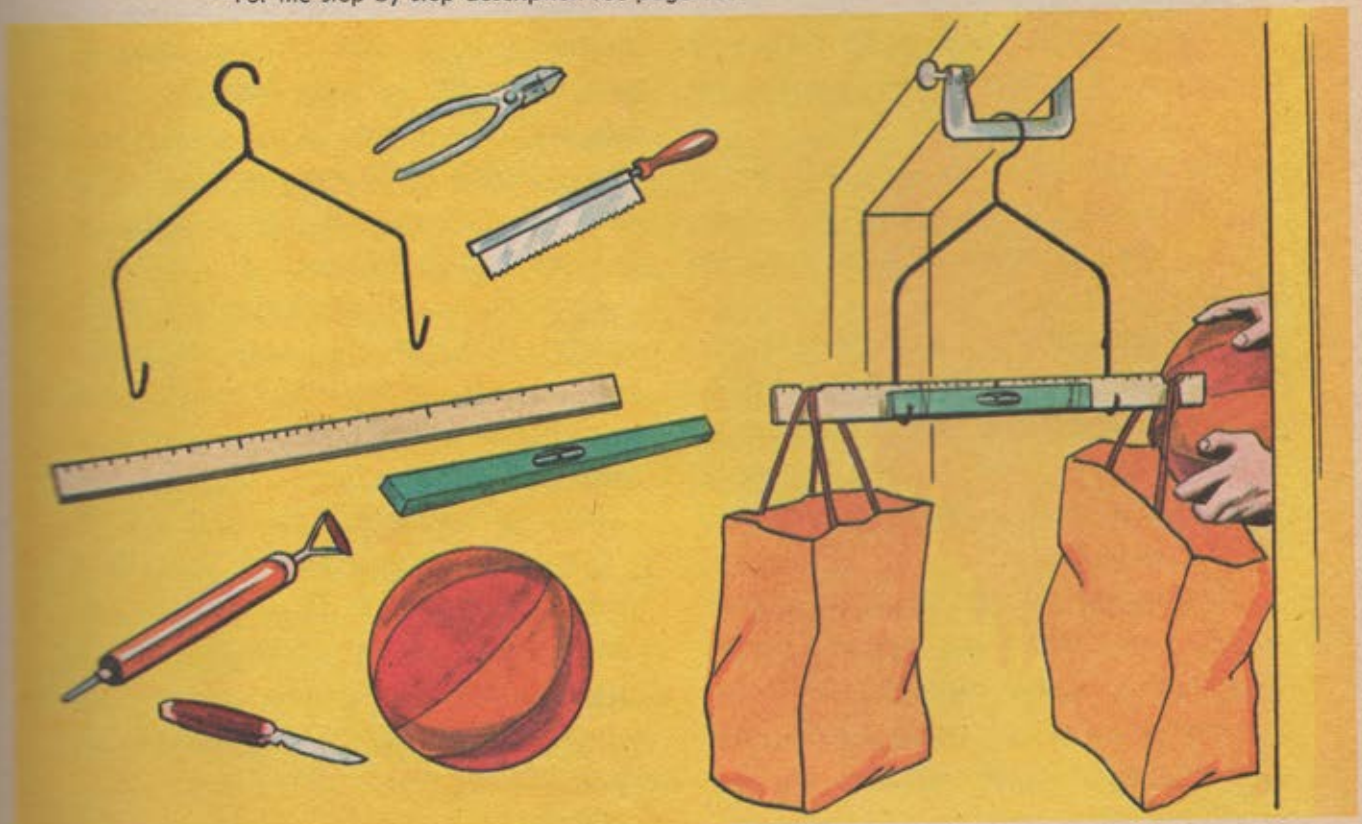
Galileo now had these facts before him: the bottom three fourths of the bottle contained water; the upper fourth contained all the air that had completely filled the bottle before the water was forced in. That air, now

squeezed into a smaller space, had become *compressed air*.

Using these facts, Galileo reasoned this way: a space filled with compressed air contains more air than the same space filled with ordinary air — air that is not compressed. If air has weight, then a volume of compressed air should weigh more than the same volume of ordinary air.

To prove his reasoning, Galileo carefully weighed the bottle with the sack wrapped around it and the water and compressed air inside. Having made this weighing, Galileo untied the sack and pulled it from the bottle. The compressed air expanded causing three quarters of a bottleful to escape. This left only one-quarter bottleful of ordinary air in the bottle. Knotting the

To prove that air has weight you can perform an experiment much like Galileo's. For the step by step description see page 10.





empty sack around the neck of the bottle, Galileo again weighed bottle, sack, water, and air. He compared the results of the two weighings and found that the first was heavier.

In both weighings, nothing happened to the bottle, sack, and water to make them change weight. The only thing that changed was the amount of air in the bottle. There was more air in the bottle during the first weighing, and this weighing was heavier. The extra air made it heavier, and this proved that air has weight.

You may wonder why Galileo did not compress air simply by pumping it into a bottle, somewhat as we compress air in a bicycle or car tyre. The answer is that the first air pump was not invented until more than half a century after Galileo performed his experiment to show that air has weight.

Although you cannot repeat Galileo's experiment exactly as he did it, you can perform an experiment that is much like the one he devised.

For Galileo's bottle, you will use a football and, for the leather sack, substitute the kind of pump used to inflate footballs.

You have to make a weighing apparatus. For this you will need a yardstick, several feet of thin, yet strong, string (fishing line is good), a coat hanger, a carpenter's level, a D-clamp, and two shopping bags.

The tools you will need are a pen-knife, a small saw, and a pair of pliers.

Cut two square notches, each one inch from an end of the yardstick. Each notch should be about half an inch wide.

Using the pliers, cut and bend the coat hanger to make a wire cradle as shown in the illustration on page 9.

Tie the carpenter's level to the yardstick as shown. The centre hairline on the glass tube of the level should be at the 18-inch mark on the yardstick. Attach the D-clamp to the top of a doorway. Place the yardstick and level in the wire cradle and hang them from the clamp. Be sure that the doorway is not drafty, because wind blowing on your experiment will make your results come out wrong.

Hang the two shopping bags on the yardstick by placing the handles of a bag in one of the notches.

Let the air out of the football. Then pump air into it just until the creases have smoothed out. The ball now should be soft when you poke it with your finger.

Carefully put the ball into one of the shopping bags. Put weights such as pebbles, nails, or sand into the other bag until the bubble in the level shows the yardstick to be hanging level. This shows that the two bags are in balance, that they weigh the same.

Remove the ball from the bag, being careful that the bag containing the weights does not lower so fast and hard as to throw your whole weighing apparatus out of kilter.

Now pump air into the ball until it is as hard as when it is ready to be used in a football game. Pumping the additional air into the ball compresses all the air in the ball. More air takes up the same space as the air that was in the ball when you weighed it.

Gently put the ball back into the



shopping bag and examine the bubble in the level. You will see that the bubble has moved toward the side on which the weighted bag is hanging. This means that the ball now weighs more than the pebbles (or other weights) that had just balanced the ball before the additional air was pumped in. The additional weight must have come from the added air.

Hold a penny in one hand and a small strip of paper in your other hand. Hold both hands the same distance

**Why does a penny fall faster than a piece of paper?**

above the floor. Let go of the penny and the paper at the same instant. Which strikes the floor first? The penny does. Now let us see why.

Let us suppose that we have a wide glass tube that is five feet long. We place a penny and a small strip of paper inside the tube, cover both ends tightly, and hold the tube upright. The penny and the paper are now resting at the bottom of the tube. We turn the tube around, so that the bottom is now the top. We do this so quickly that the penny and the piece of paper begin to fall from the top at the same instant. The penny falls rapidly to the bottom, while the strip of paper glides slowly downward.

Let us now connect the glass tube to an exhaust pump that pumps almost all the air out of the tube. (We would like to take all the air out of the tube, but there is no pump that can do this.) Again we quickly turn the tube around. This time the strip of paper falls as fast as the penny and strikes the bottom at

the same instant. Why? Something must have slowed the fall of the paper strip the first time we made it fall; and whatever slowed the paper the first time did not do so the second time. The only change we made in the glass tube and its contents was to remove the air. So, it must have been the air in the tube that slowed the fall of the paper.

Air is a kind of matter and therefore takes up space. When the tube was filled with air, the penny, which is heavier than the small strip of paper, could more easily push its way down through the air.

We have demonstrated that air takes up space; air also has weight. These are characteristics of all matter. Air has another characteristic that is shared by all gases: It is *elastic*. This means that air is springy. It will spring back to its original volume after being compressed or squeezed.

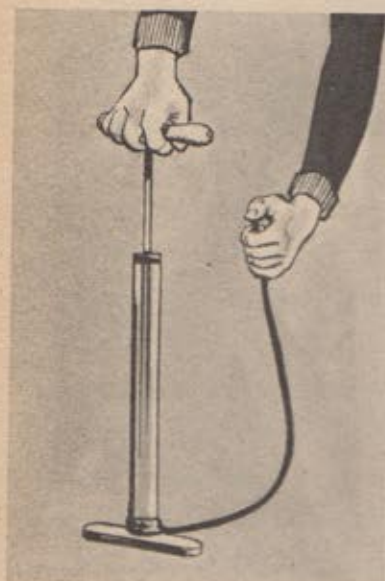
**How can you show that air is elastic?**

You can prove that air is elastic by means of a bicycle pump or a pump used to inflate footballs. To do this, pull the pump handle all the way out so that air will enter the pump. Now hold a finger tightly over the nozzle of the pump and push the handle into the pump as far as you can. Suddenly let go of the handle. It will spring outward.

When you pushed the handle in, you compressed the air in the pump. When you let go of the handle, it sprang outward because the air behind it in the pump was springing outward. This springiness proves that the air inside the



pump is elastic. Since the air inside the pump was drawn in from the outside, it was not different from the air outside. Thus, the outside air must be springy, or elastic, too. All air is elastic. This is the reason water rose a short way into the glass when you did the first experiment in this book. The air was compressed by the water pressing against it.



You can easily prove that air is elastic — springy — by compressing it within a bicycle-tire-pump.

Water is made of hydrogen and oxygen, two of the gases that are found in the air.

**What is water?**

It is a wonderful fact of nature that two gases can combine to make a liquid, and this is what happens when oxygen and hydrogen are combined in the proper way. To combine hydrogen and oxygen, a scientist puts two volumes (a volume of a gas, liquid, or solid is the amount of space it takes up) of hydrogen and one volume of oxygen into a sturdy container, perhaps a flask of very thick glass. Then he sets off an electric spark within the container to produce an explosion. After the explosion, drops of water will appear on the inside of the container and there will be no more

hydrogen or oxygen left. The water formed contains two volumes of hydrogen for every one volume of oxygen. In fact, all water everywhere contains two volumes of hydrogen for every one volume of oxygen. Samples of water taken from a raindrop, from a faucet, or from the bottom of the ocean will all have the same amounts of these two gases.

Because water is always the same, scientists can write a formula for it. To the scientist, water is  $H_2O$ . This simply

**What is the scientific name for water?**

means that water has two volumes of hydrogen (H) for every one of oxygen (O). The next time your friends visit you, offer them a glass of  $H_2O$  to drink. They'll probably be surprised when you come back from the kitchen with a glass of plain water.

We think of water as a liquid, but water can also be a solid or a gas. Solid, liquid, and gas are the three

**When is water not wet?**

*states of matter*. Water in the solid state is called ice. Ice is not wet. This may surprise you, but the reason ice feels wet when you touch it is that the warmth of your hand melts the ice, changing some of it to water. In the gaseous state water is called water vapour. You cannot see water vapour because it is an invisible gas, but when water vapour cools you can see a cloud of steam. Steam is made of tiny droplets of water in the air.

You can easily change ice to water, water to water vapour, and water vapour to steam. Take four or five ice



cubes and put them in the bottom of a tea kettle. Now put the tea kettle on the stove. Leave the cover of the tea kettle off so you can see what happens. Soon all the ice has melted and turned into water. Now put the cover on the tea kettle. In a short time the water will begin to boil and there will be a cloud of steam near the spout. Now look closely at the end of the spout. Between the cloud of steam and the spout is a small space that seems to be empty. But it is not empty. It is filled with water vapour. You can prove that this invisible substance is a form of water by turning some of it back into a liquid. Wrap a towel or pot holder around the handle of a metal spoon and hold the bowl of the spoon in front of the tea kettle spout. Drops of water will form on the spoon. You can change the drops of water back into ice by putting the spoon in the freezer of a refrigerator. Later we will see that a process very much like this is going on all the time in nature.

If someone were to ask you which is heavier, a bucket of ice or a bucket of water, you might very well choose the bucket of ice because you probably think of solids as being heavier than liquids. But if you chose

**Why is ice lighter than water?**

heavier, a bucket of ice or a bucket of water, you might very well choose the bucket of ice because

you probably think of solids as being heavier than liquids. But if you chose

When you melt ice, it turns into water.



When you boil water, it turns into water vapour and steam.



When you cool water vapour, you can turn it back into water.



the ice you would be wrong. A bucket of ice is lighter than a bucket of water. Water is different from most other liquids because when it freezes and becomes solid, it becomes lighter than when it is a liquid.

You can demonstrate this very easily. Take two metal measuring cups like the ones your mother uses to measure flour.



The water reaches the "1 cup" mark.



Water expands when it freezes.

A cup of ice, when melted, does not make a cup of water.





Fill them with water to the mark that says "one cup." Now put one cup of water in the freezer of your refrigerator and leave it there until the water has turned to solid ice. When all the water has frozen, you will see that the ice sticks up above the "one cup" mark. This is because water expands as it freezes. Now chip away all the ice above the "one cup" mark. Now you have one cup of ice. Let it stand until all the ice has melted. When the ice has completely melted, look at the level of the water. It no longer reaches to the "one cup" mark. A partly filled cup of water weighs less than a full cup. Therefore a cup of ice must weigh less than a cup of water. If you have a scale you can measure the difference.

Because ice is lighter than water, it floats. When you put ice cubes in a glass of water, the ice bobs up and down for a second or two, and

**Why aren't fish frozen into the ice of lakes and rivers?**

then floats at the top of the water. Ice on frozen lakes and rivers also floats at the top of water. This fact is very important to plants and animals that live in the water. Below the ice, the living things can continue to live. The ice acts as a shield, protecting the water beneath it from the cold air above. If the ice were heavier than water, the bottom of the lake would fill with ice. Eventually, the whole lake would be frozen from bottom to surface and all the ani-

As ice is lighter than water, it floats. This permits life to go on in frozen lakes and rivers.

mals—fish, frogs, salamanders, water snakes, and others—and the plants living there would freeze and die. Furthermore, in the spring, the warm sunlight would not be able to melt all the ice as it can because the ice is only at the surface.

You know that steel is much heavier than water, yet you can float a piece of steel on water! It sounds impossible, yet it is really very easy to make a steel needle float. All you need is a glass of water, a fork, and a needle from your mother's sewing basket.

Wash the fork and needle with soap. Be sure to rinse off all the soap. Place the needle on the fork and lower the fork slowly into the glass of water. The needle will float. Why does this happen?

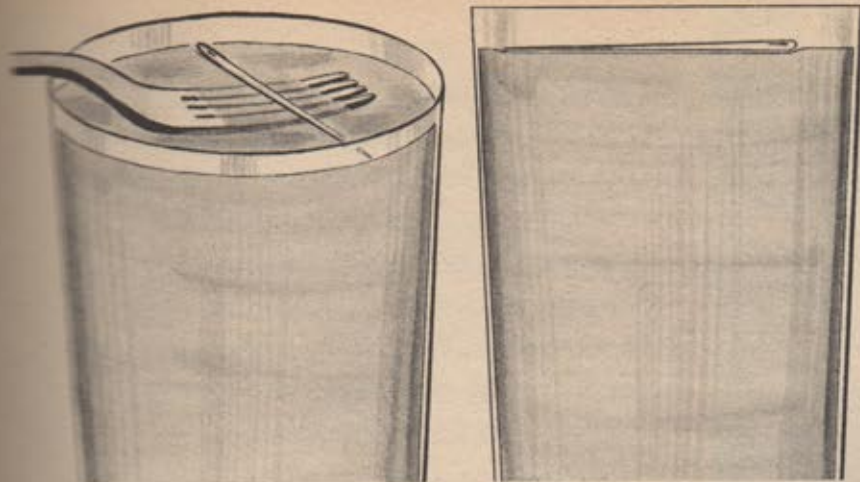
Water is made up of very small particles called molecules. Each molecule is made up of two atoms of hydrogen and one atom of oxygen. A molecule of water is so small that it is impossible to

**How can you float a piece of steel?**

float a piece of steel on water! It sounds impossible, yet it is really







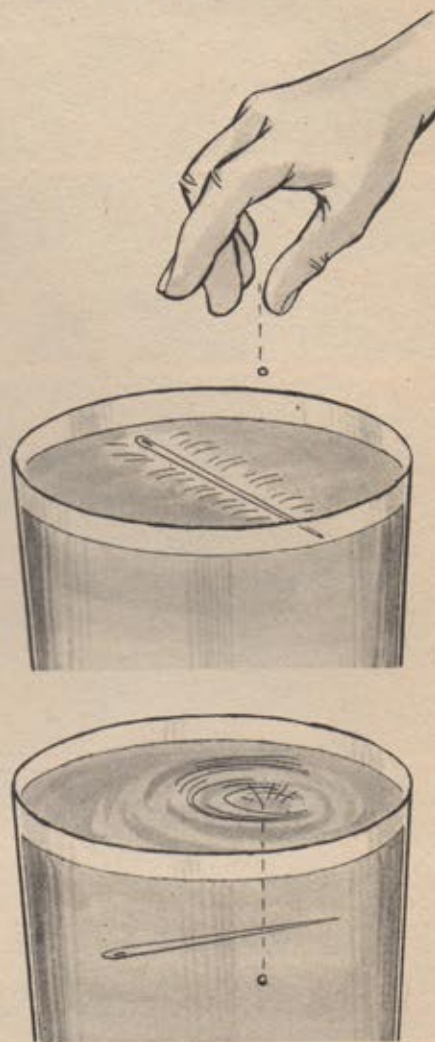
Surface tension allows the steel needle to float (illustrations at left). Dropping a few grains of soap powder into the glass lessens the surface tension and the needle sinks (illustration below).

see it even with the most powerful microscope. Molecules cling together. Those on the surface cling together so tightly that they form a film, or skin.

Imagine a large group of children in a schoolyard. Each child has his arms about the waists of the children next to him. The children on the outside of the group form an unbroken chain. These children are also held by some of the children next to them on the inside of the group. As a result, the children on the outside will form a strong ring about the others. If someone tried to walk into the group, he would have a hard time pushing through the ring of children on the outside. They would probably be able to hold him out.

The molecules at the surface of the water are like the children in the ring around the rest of the group. The surface molecules cling together so tightly that they can hold the steel needle afloat. Scientists have a name for the strong clinging together of the molecules at the surface of a liquid, such as water. They call it *surface tension*.

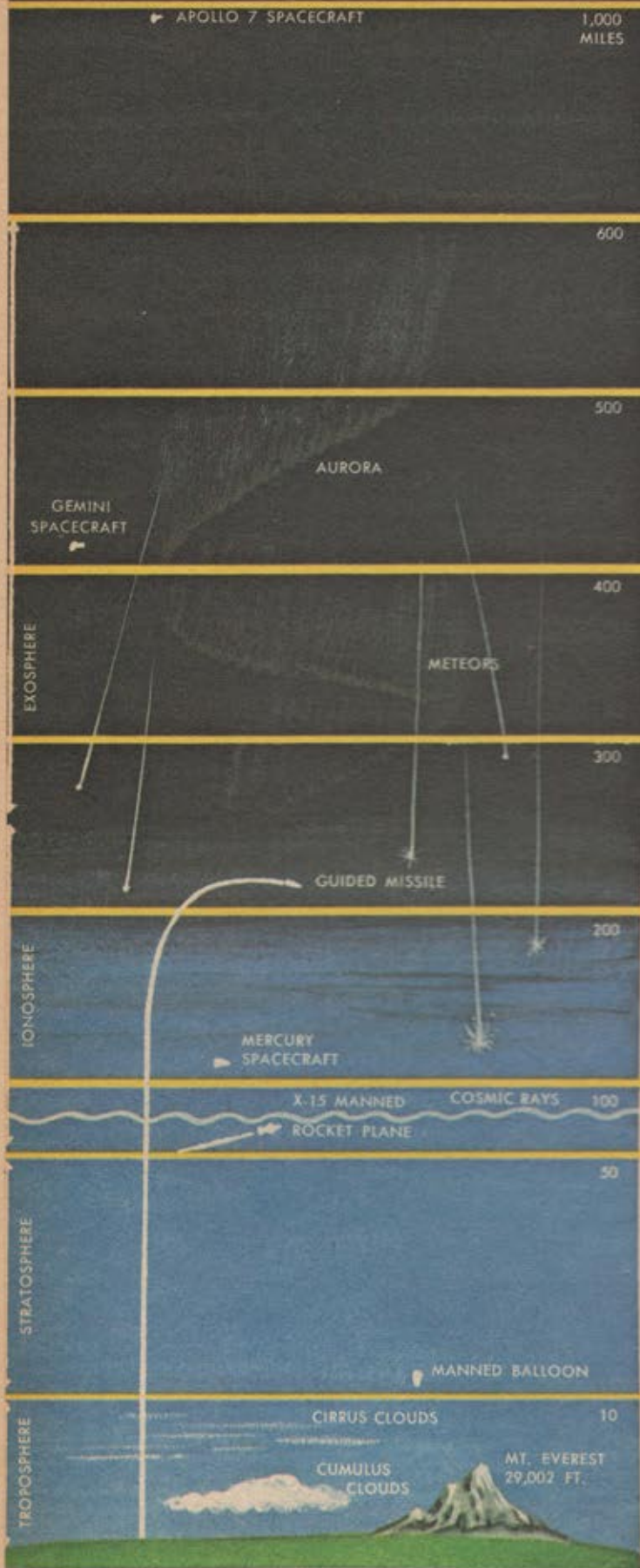
If you look closely at the floating needle, you will see the surface film bending under the weight of the needle.



If the surface film is broken, the needle will immediately sink to the bottom of the glass. Push the floating needle through the surface of the water, and it will sink to the bottom.

If you lessen the surface tension, you will not be able to float a needle on water. Let us try an experiment that will prove this. Take the needle out of the water and dry it. Use the fork to float the needle again. Now, drop a few





The earth's ocean of air is divided into layers.

grains of soap powder into the glass. The needle sinks. What happened? The soap lessened the surface tension so that the molecules at the surface no longer clung together strongly enough to hold the needle afloat. Think of the children in the schoolyard. Suppose someone told most of the children making up the outside ring to remove their arms from the waists of the children next to them. The outside ring would no longer be strong, and anyone wishing to walk into the group could easily do so. Although molecules have no arms, you might think of the action of the soap as one that caused each molecule at the surface to remove its "arms" from the molecule next to it.

When your mother puts soap into the washing machine, she is reducing the surface tension of the water so that the water can soak into the clothes and float away dirt more easily.

## Air and Water in Nature

The earth's ocean of air, the atmosphere, extends about 600 miles above the earth's surface and is divided into layers. Let us pretend that we are aboard a rocket that is rising from the earth's surface and passing through all the layers of the atmosphere. We begin our journey in the lowest layer of air. This layer, called the *troposphere* (trop'-uh-sfeer), is about seven miles thick. Not even the

**What are the layers of the atmosphere?**

600 miles above the earth's surface and is divided into layers.



highest mountains rise above the troposphere. When we leave the troposphere, we enter the layer called the *stratosphere* (strat'-uh-sfeer). This layer extends to about 53 miles above the earth. Here the air is very thin, clear, and cold. Our rocket leaves the stratosphere and enters the next layer, the *ionosphere* (eye-on'-uh-sfeer). This layer extends from 60 miles to 250 miles above the earth's surface. It is called the ionosphere because here the sun's rays break up the atoms of air into electrically charged particles called ions. Here the air is thinner than in the stratosphere. The uppermost layer of the atmosphere is called the *exosphere* (eks'-o-sfeer). The air continues to become thinner until, at about 600 miles above the earth's surface, there are no more air particles. When our rocket has passed through the exosphere, we are in outer space. The entire atmosphere has been left behind us.

More than 99 percent of the air is in the lowest 20 miles.

We learned that the sun's rays break up the air in the ionosphere into electrically charged particles called electrons and ions. If you live in the far northern or far southern parts of the earth you have probably seen great curtains and streamers of light moving across the night sky. These shifting lights are made of electrons and ions moving in the ionosphere. We call these the Northern Lights and the Southern Lights, but the scientific names for them are *aurora borealis* and *aurora australis*.

**What are the auroras?**

Obtain a toy balloon at least ten inches in diameter when blown up. Blow the balloon up and tie the rubber at the mouth-

**How can you show that cool air takes up less space than warm air?**

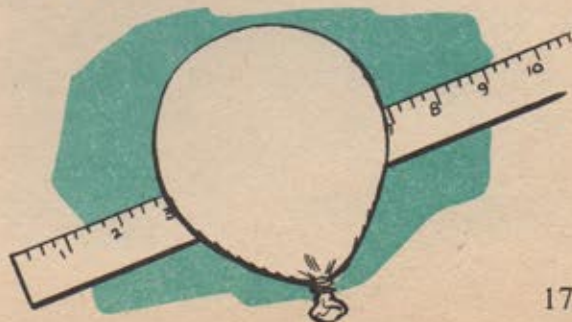
piece of the balloon into a *double knot*. This is to make sure that no air escapes. Simply tying the balloon closed with string will not seal it tightly enough.

Place a ruler or yardstick on a table and put the balloon upon it, measuring the diameter of the balloon. Write down the measurement.

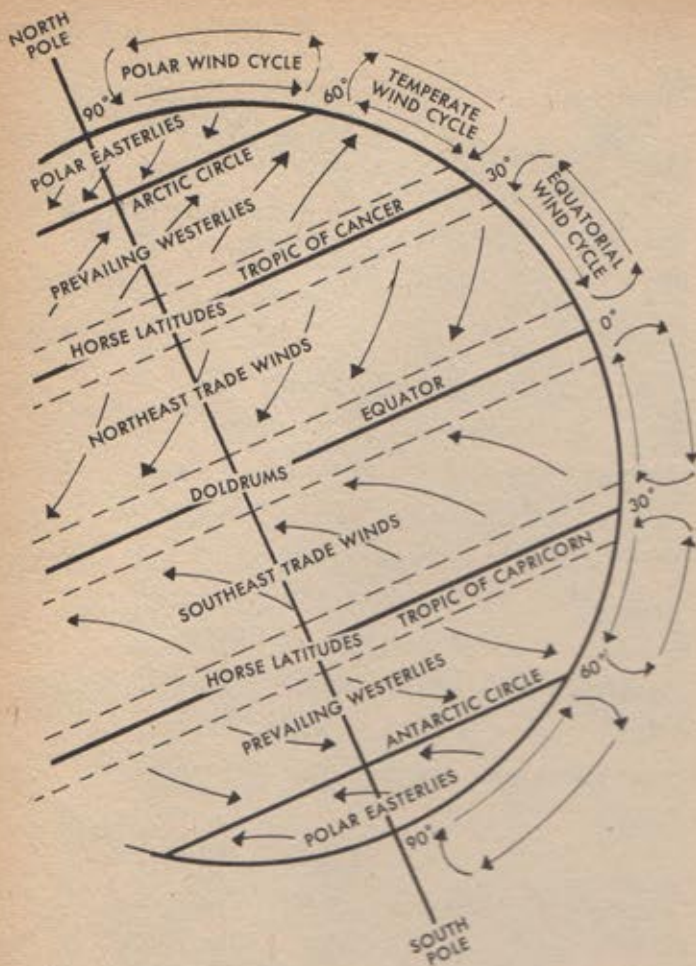
Then, place the balloon into a freezer or into the freezing compartment of a refrigerator. Leave the balloon there overnight.

Immediately upon removing the balloon from the freezer, measure it again. You will find that it is smaller. (As soon as you have measured it, put the balloon back into the freezer.)

The air in the balloon contracted, or shrank. When you blew up the balloon, the air in it was at the temperature of your lungs, from where the air came. This temperature is approximately 98° F. After you took it from the freezer, the air in the balloon was somewhere near 0° F. Since the cooler balloon is smaller, the air filling the cool balloon takes up less space than the same air when warm. Therefore, when any air is cool, it takes up less space than when warm.







These are the six great wind belts of the world. Within each belt, local winds may temporarily blow backward or forward in any direction.

it is as small as the cool balloon. Since some air was let out of the warm balloon, it now contains less air than the cool balloon.

Think again. If you weigh both balloons, which will weigh less? The warm balloon, of course, since you let out some of its air. But both balloons are now the same size (even though one has more air in it), therefore, the heavier balloon must contain heavier air—the cool air.

Obtain another balloon the same size as the one you just used. Blow this balloon up to the same size as the one whose size you wrote down. Twist and hold the rubber at the mouthpiece so that no air can escape, but do not knot it this time.

The balloon you just blew up contains as much warm air as did the warm balloon in the previous experiment.

Again remove the cool balloon from the freezer. Now think. Suppose you were to weigh both balloons, which would weigh more? Neither, because you blew the same amount of air into both.

Let air out of the warm balloon until

We have learned that wind is moving air. Now let us find out what makes air move in large amounts across the surface of the earth.

In the experiment you just performed you showed that warm air is lighter than cool air. When air is cool, it is heavy. Heavy air sinks to earth, and pushes warm light air upward. For short, we say that warm air rises, but we must keep in mind that the warm air rises only because it is pushed up by the sinking of heavy cool air.

Because the region around the earth's equator is the warmest part of the earth, the air above it is warmer than the air over other regions. This warm air is pushed upward by the cooler, heavier



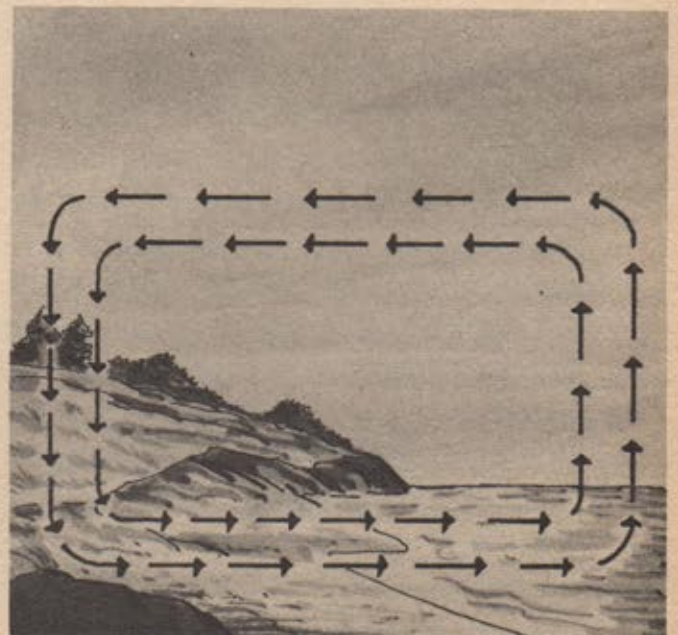
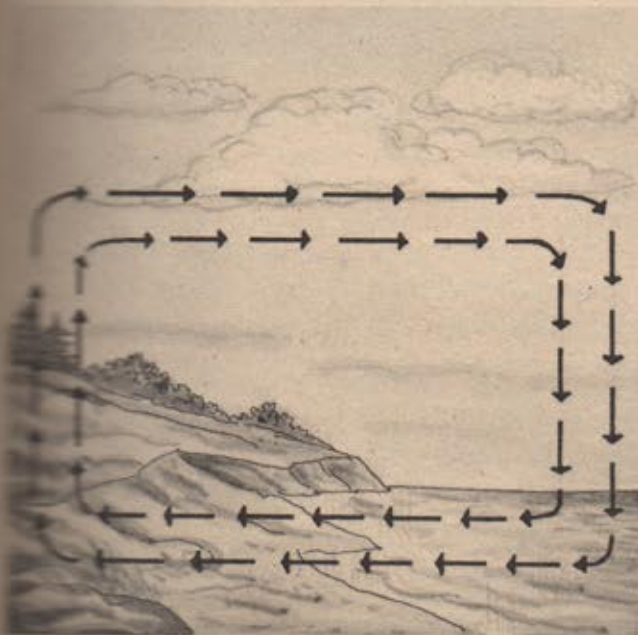
air that flows in north and south of the equator. As this cool air warms, it, in turn, is pushed upward by cool air moving in. The rising air above the equator flows northward and southward, becoming cool as it moves. Eventually, this cooled air sinks, taking the place of the air flowing in toward the equator.

These broad movements of air along the surface of the ocean toward the equator are called the trade winds. These winds do not actually blow directly north or south, because the earth is turning from west to east faster than the air moving over its surface. As a result, the earth turns beneath the southward-moving winds, causing them to move from northeast to southwest and the winds are known as the northeast trade winds. In the earth's Southern Hemisphere, the directions are reversed; the trade winds blow from the southeast to the northwest. And the winds are known as the southeast trade winds.

On sunny days land surfaces such as beaches and fields become warmer than nearby water surfaces such as lakes and oceans. The air in contact with the land is heated, expands, and becomes lighter. Cooler, heavier air from over the water flows toward the land and pushes the lighter air upward. The rising warm air flows toward the water taking the place of the cool air. The warm air that rises and moves out over the water becomes cooled and therefore heavier. This cool air sinks down to the surface of the water where it is further cooled. Then it flows toward the land to push upward the air that flowed in from the water and has since become warmed by contact with the land. This process, in which air moves from water to land and back to water again is called the *wind cycle*. A cycle is a process that repeats itself over and over again.

At night, directions of the wind cycle

Wind blows toward land during the day and toward water at night.





are reversed. The land surfaces such as sand, soil, and rock, which are quickly warmed by the sun also cool quickly when the sun no longer shines on them. Water surfaces are warmed slowly and cool slowly. After sunset, the land surfaces soon become cooler than the nearby water surfaces. The air over the water is warmed by contact with the water, and cool air from the land flows over the water, pushing the warm, light air upward. This warm air flows over the land where it becomes cooled, sinks, and flows back over the water again.

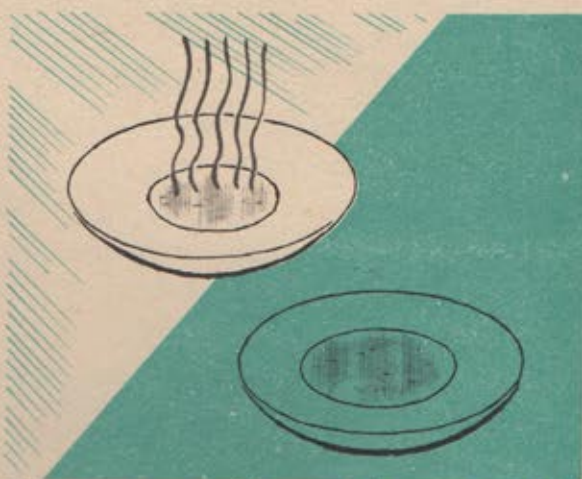
The cool air that flows landward from the water during the day is called a sea breeze or lake breeze. It is this breeze that makes seashores and lakeshores so comfortable during hot weather.

We learned that water is made of very small particles called molecules. Molecules are constantly moving about and bumping into each other. Some of the molecules at the surface of the water are bumped so hard that they break away and fly off into the air. Most of these molecules fall back, but some are bumped so hard and fly so fast that they are caught among the molecules of which air is made. These water molecules are bumped along among the air molecules and do not return to the water from which they came.

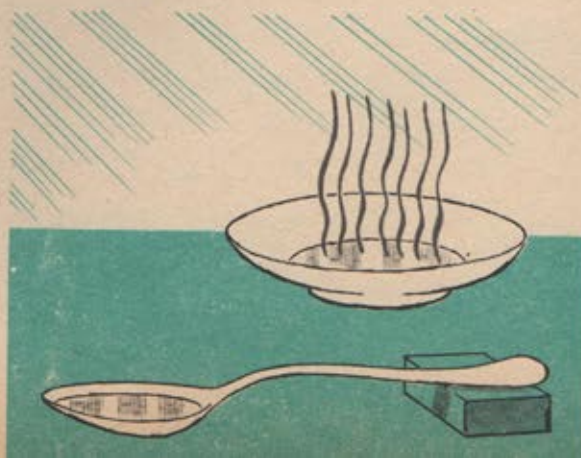
Let us imagine again the group of children in the schoolyard. Remember that they had their arms around each others' waists. Now suppose that all the children began to jump back and forth.

Sooner or later, some of the children on the inside of the group would bump into those forming the ring around the whole group. If those on the inside bumped hard enough, they would cause one of the children forming the outside ring to loosen his grasp on his neighbours' waists; and the force of the bump would knock him right out of the group. Another child would take his place, but sooner or later this second child would be bumped out of the group, too. As this went on, the group would grow smaller and smaller.

As molecules continue to fly off the surface of water, the amount of water left behind becomes less and less. This



If you put a saucer with water in the sunlight and the same size saucer with water in the shade, you will find that water evaporates faster in a warm place (above). If you put the same amount of water in a spoon and in a saucer and put them next to each other, you will find by checking the time that water evaporates faster from a larger surface than a smaller one (below).





process in which a liquid loses molecules to the air is called *evaporation*. You have probably seen a puddle of water on the sidewalk or on a flat roof "dry up." This drying was really evaporation in which all the molecules of water in the puddle flew off into the air.

Ordinarily, evaporation takes place so slowly that you do not notice it. If you fill a saucer with water and leave it uncovered in a room at ordinary temperature, several days will pass before all the water has evaporated. If you put the saucer into a warm place, such as in bright sunlight, the water may evaporate in a few hours. If the water were poured into a saucepan and heated on a stove, the water would evaporate in a few minutes. Boiling is a kind of very fast evaporation. From these facts, you can see that heat makes evaporation take place faster. Why does this happen? Because when a liquid is heated, its molecules move around faster and more of them are sent flying off into the air.

On a hot, muggy summer day, people

often say, "It's not the heat, it's the humidity." What do they mean? Humidity is a word that describes the amount of water vapour in the air. When there is a lot of water in the air we say the humidity is high. When the air is very dry we say the humidity is low. We feel uncomfortable if the humidity is too high. The perspiration on our bodies does not evaporate easily because there is a lot of water in the air. But too low humidity is not good either. In the winter when our houses are heated, the air may become

Water vapour in the air condenses and forms beads of water on the side of the container filled with ice.



so dry that indoor plants die unless the humidity is increased.

You may have heard a weather report in which the announcer said, "The relative humidity is 70 percent." This means that the air contains 70 percent, or seven tenths, as much water as it can hold. When air contains all the water it can hold, we say that it is *saturated*.

Warm air can hold more water than cold air. When warm, moist air is cooled it gives up some of its water. You can see this in the summertime when the dew forms on the grass after sundown. The grass cools off after the sun goes down. The air comes in contact with the cool grass, and it, too, is cooled. The cool air can no longer hold all the moisture, and some of the water leaves the air. We can see it as beads of water on the blades of grass. Scientists say that the water vapor in the air has *condensed*. You can condense some of the water vapour in the air if you fill a drinking glass or tin can with ice and place it in the kitchen, or a fairly warm room. Soon beads of water will form on the sides of the container. When the air comes into contact with the ice-cold container, the air is cooled and has to give up some of its moisture.



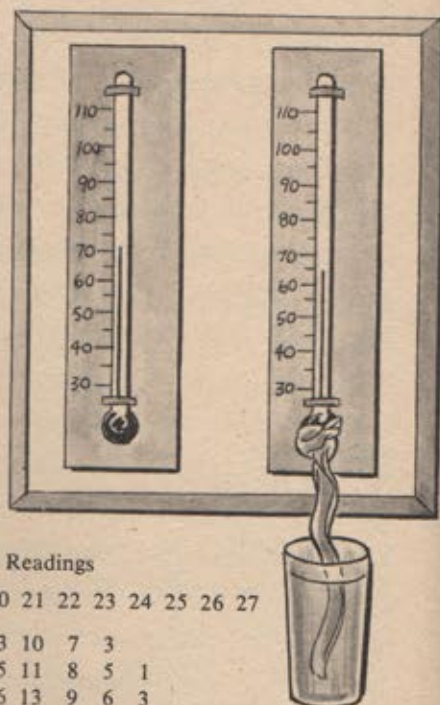
Obtain two household thermometers.

**How can you measure humidity?**

Cut a strip one inch wide and five inches long from an old towel or other absorbent cloth. Wrap one end of the strip around the bulb of one of the thermometers and tie the cloth in place with a piece of string. This is your *wet-bulb thermometer*, the other is your *dry-bulb thermometer*. Hang both thermometers at the same level. Place a glass of water beneath the thermometer with the piece of cloth so that half the length of cloth is in the water. When the water has risen to the level of the thermometer's bulb, place an electric fan so that it will blow on the bulbs of both thermometers, and then turn the fan on. (If an electric fan

is not available, fan the thermometers vigorously with a sheet of cardboard.) After the fan has been blowing air on the thermometers for five minutes, note the reading of each thermometer and write it down.

You can use the table on this page



Dry-Bulb Reading

Difference Between Wet- and Dry-Bulb Readings

↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27						
65	95	90	85	80	75	70	66	62	57	53	48	44	40	36	32	28	25	21	17	13	10	7	3										
66	95	90	85	80	76	71	66	62	58	53	49	45	41	37	33	29	26	22	18	15	11	8	5	1									
67	95	90	85	80	76	71	67	62	58	54	50	46	42	38	34	30	27	23	20	16	13	9	6	3									
68	95	90	85	81	76	72	67	63	59	55	51	47	43	39	35	31	28	24	21	17	14	11	8	4	1								
69	95	90	86	81	77	72	68	64	59	55	51	47	44	40	36	32	29	25	22	19	15	12	9	6	3								
70	95	90	86	81	77	72	68	64	60	56	52	48	44	40	37	33	30	26	23	20	17	13	10	7	4	1							
71	95	90	86	82	77	73	69	64	60	56	53	49	45	41	38	34	31	27	24	21	18	15	11	8	5	3							
72	95	91	86	82	78	73	69	65	61	57	53	49	46	42	39	35	32	28	25	22	19	16	13	10	7	4	1						
73	95	91	86	82	78	73	69	65	61	58	54	50	46	43	40	36	33	29	26	23	20	17	14	11	8	5	2						
74	95	91	86	82	78	74	70	66	62	58	54	51	47	44	40	37	34	30	27	24	21	18	15	12	9	7	4						
75	96	91	87	82	78	74	70	66	63	59	55	51	48	44	41	38	34	31	28	25	22	19	16	13	11	8	5						
76	96	91	87	83	78	74	70	67	63	59	55	52	48	45	42	38	35	32	29	26	23	20	17	14	12	9	6						
77	96	91	87	83	79	75	71	67	63	60	56	52	49	46	42	39	36	33	30	27	24	21	18	15	13	10	7						
78	96	91	87	83	79	75	71	67	64	60	57	53	50	46	43	40	37	34	31	28	25	22	19	16	14	11	9						
79	96	91	87	83	79	75	71	68	64	60	57	54	50	47	44	41	37	34	31	29	26	23	20	17	15	12	10						
80	96	91	87	83	79	76	72	68	64	61	57	54	51	47	44	42	38	35	32	29	27	24	21	18	16	13	11						
82	96	92	88	84	80	76	72	69	65	62	58	55	52	49	46	43	40	37	34	31	28	25	23	20	18	15	13	10					
84	96	92	88	84	80	77	73	70	66	63	59	56	53	50	47	44	41	38	35	32	30	27	25	22	20	17	15	12					
86	96	92	88	85	81	77	74	70	67	63	60	57	54	51	48	45	42	39	37	34	31	29	26	24	21	19	17	14					
88	96	92	88	85	81	78	74	71	67	64	61	58	55	52	49	46	43	41	38	35	33	30	28	25	23	21	18	16					
90	96	92	89	85	81	78	75	71	68	65	62	59	56	53	50	47	44	42	39	37	34	32	29	27	24	22	20	18					
92	96	92	89	85	82	78	75	72	69	65	62	59	57	54	51	48	45	43	40	38	35	33	30	28	26	24	22	20					
94	96	93	89	86	82	79	75	72	69	66	63	60	57	54	52	49	46	44	41	39	36	34	32	29	27	25	23	21	19	17			
96	96	93	89	86	82	79	76	73	70	67	64	61	58	55	53	50	47	45	42	40	37	35	33	31	29	26	24	22	20	18			
98	96	93	89	86	83	79	76	73	70	67	64	61	59	56	53	51	48	46	43	41	39	36	34	32	30	28	26	24	22	20			
100	96	93	90	86	83	80	77	74	71	68	65	62	59	57	54	52	49	47	44	42	40	37	35	33	31	29	27	25	23	21			

Practice examples:

Dry Bulb 75	Wet Bulb 72	Difference 3	Relative Humidity 87 per cent
Dry Bulb 71	Wet Bulb 51	Difference 20	Relative Humidity 21 per cent
Dry Bulb 82	Wet Bulb 71	Difference 11	Relative Humidity 58 per cent



to work out the relative humidity. In the column headed "Dry-Bulb Reading," find the reading of your dry-bulb thermometer. Subtract from this number the reading of your wet-bulb thermometer. Find this difference in the top row marked "Difference Between Wet and Dry-Bulb Readings." Run your finger down the column below that number until you come to the number that is in line with your dry-bulb reading. This number is the relative humidity. Look at the examples of this calculation given below the chart.

It will be fun to do this experiment outdoors. If it is a windy day, you won't need a fan. Just let the wind blow on the thermometers. When you have found the relative humidity, listen to the next radio weather report for your area and compare your measurement of relative humidity with the one given by the Weather Bureau.

When you climb out of the water after a swim on a windy summer day, the wind on your wet body seems much colder than it did before you went into the water. Why?

**How does moving air help cool your body?**

entering the air as water vapour. In hot weather

We learned that heat causes water to evaporate. Heat makes the water molecules move faster so that many are driven off the surface of the water. In driving off the molecules, heat is used up. The heat of your body is used up when water evaporates from your skin. More heat passes from your skin into the water, and the loss of this heat cools your skin. We have seen that wind speeds evaporation. Therefore, your

wet body cools rapidly when the wind is blowing upon it.

Evaporation controls your body's temperature. When you become very warm, you give off water through the pores of your skin. This water is perspiration. As perspiration evaporates it uses your body heat and thereby makes your skin feel cooler. If you sit in a breeze, where perspiration may evaporate more rapidly, you cool off much faster.

Water is constantly evaporating and entering the air

**How do desert plants store water?**

as water vapour. In hot weather

we can feel this happening when the perspiration from our bodies evaporates and makes us feel cooler. Plants also lose water by evaporation. Most of the water evaporates from tiny openings in the leaves. More water is taken in from the soil by the plants' roots to replace water lost by evaporation. In hot dry regions, such as deserts, evaporation takes place very fast and there is very little water in the soil. If desert plants had leaves, they would lose more water than they could replace from the soil. Plants that live in deserts must have special features to enable them to keep water. Cactus plants are very well suited to do this. Most cactus plants have no leaves from which the water can evaporate. Instead, they have thick fleshy stems that can store water. One kind of cactus, the barrel cactus, holds several quarts of water in its stem, and it has saved the lives of many thirsty travelers lost in the desert. The barrel cactus and many other cactuses are covered with



Because cactus plants have no leaves, they lose less water by evaporation.



bristles or spines that shield the tiny openings in the stem from which water might evaporate. One kind, called the old man cactus, is completely covered with a mass of grey "hair" that protects it from the sun and thus helps to keep the water from evaporating. And some kinds of cactus have a coating of wax over the stem that keeps water from evaporating.

When air is cooled to the dew point,

**What are clouds?** water vapour condenses on particles of dust or smoke that are floating in the air. The droplets of water formed in this way are very small and can float in the air for a long time. Clouds are made of these droplets of water. When clouds form in air that is touching the surface of the earth, we say that a fog has formed. Fog, then, is really low clouds.

Not all clouds are made of droplets of water. Sometimes air from close to the earth is swept quickly upward to heights of five miles or more. The rising air is quickly cooled below the freezing point. As a result, the condensing water vapour is frozen, and clouds of tiny ice crystals are formed. If you have

ever seen layers of rippled white clouds very high in the sky—the kind of clouds that are called "a mackerel sky"—then you have seen ice clouds.

Three things are necessary to make clouds form:

**How can scientists make rain?** water vapour, a dew point, and

some small particle for the water vapour to condense upon. If the temperature of the air falls below the dew point, the droplets of water that form a cloud join to form drops of water so large that they can no longer float in the air. These drops fall as rain.

Sometimes, the temperature in a cloud falls low enough for raindrops to form, but the cloud droplets do not join to form raindrops. When this happens, we say that the cloud is *supercooled*. One of the ways to make raindrops form in a supercooled cloud is to cool it even more suddenly. This can be done by flying an aeroplane over the cloud and dropping small pellets of dry ice into the cloud. (Dry ice is frozen carbon dioxide gas. You have seen dry ice used in soda fountains and by vendors of ice cream to keep the ice cream cold.) The temperature of dry ice is  $-110^{\circ}$  Fahrenheit. In the supercooled cloud, the droplets of water near the falling dry ice pellets are cooled so low that many of the droplets condense to form raindrops. Many times, when these raindrops form, they cause others nearby to form. In a short time, the whole cloud condenses and falls as rain. Other times, only a few raindrops form



directly in the path of the falling dry ice pellets, and the cloud continues to float in the air.

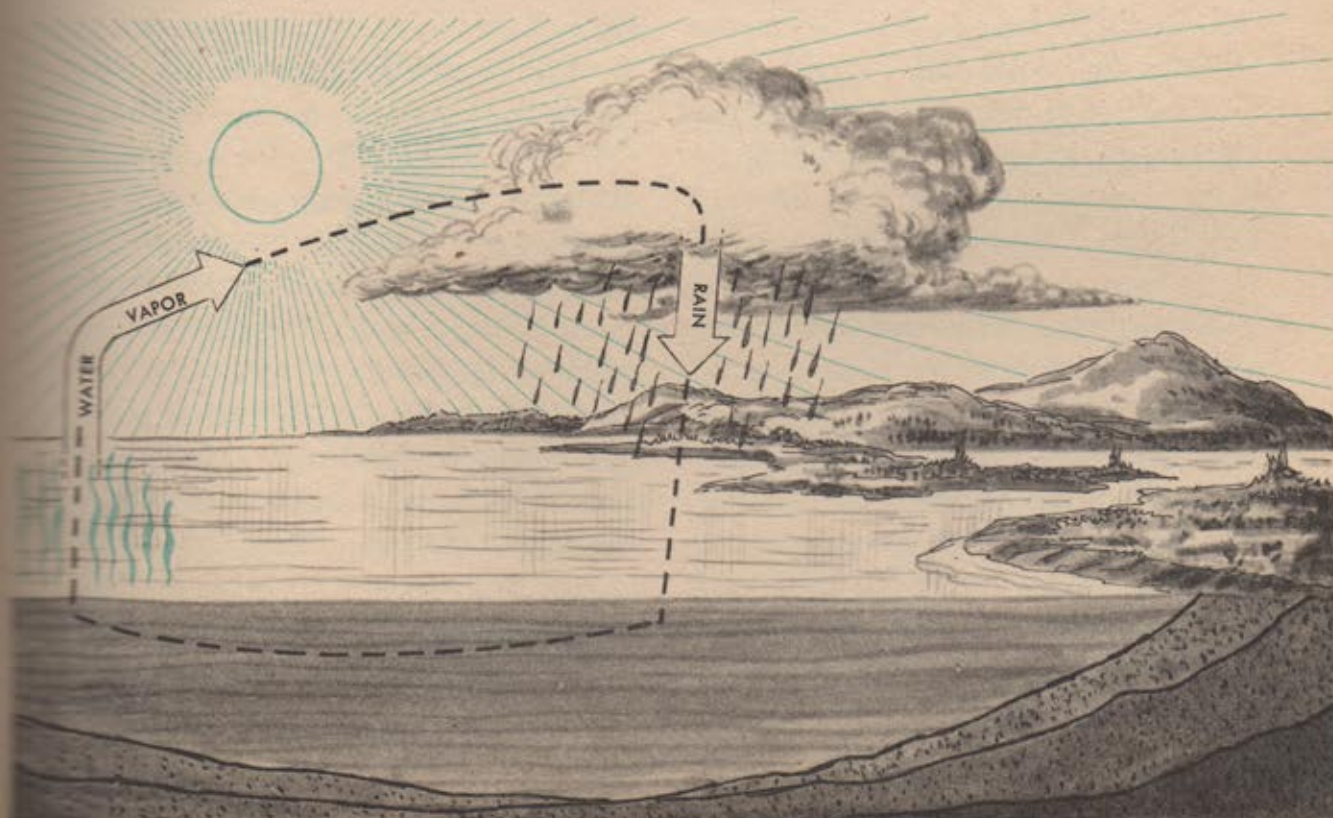
There is another way to make rain. We learned that the droplets of water vapour form around particles of smoke and dust. In much the same way, the cloud droplets can collect around certain kinds of particles to form drops of rain. One kind of particle is made of a chemical called silver iodide. Silver iodide is a solid substance that looks like brown salt. When crystals of silver iodide are placed in a small furnace and heated, they break up into very small particles that rise along with hot air through the furnace's chimney until they enter a cloud. Here they provide centres around which the water droplets may collect to form raindrops.

Putting ice pellets or silver iodide

crystals into clouds is called "seeding" the cloud. If we could learn the proper way to seed clouds so that they would always fall as rain, this knowledge would be of great value to man. By seeding clouds, we could put an end to droughts that every year in some part of the world cause food crops to dry up and be lost. Even in times of severe drought, when no rain falls for weeks or months, clouds usually float over the sun-dried land. Successful seeding of these clouds could provide the rain needed to make the crops grow.

Imagine that you are in a spaceship looking down at the earth. **What is the water cycle?** You can see many clouds below. Some of the clouds disappear and new ones appear where none were before. You are

Water from the earth's land, lakes, rivers, streams and, particularly, its oceans is evaporated by the heat of the sun. As invisible water vapor it rises into the air, cools to form clouds that produce rain or snow that again fill the earth's land, lakes, rivers, streams, and oceans.





seeing part of what scientists call the *water cycle*. The water cycle is the change of liquid water to water vapour and back to liquid water. These changes occur over and over again. As you already learned, a cycle is something that continually repeats itself. Earlier you did an experiment in which you changed water to an invisible vapour and then back to a liquid again. This process is going on all the time in nature.

Let's take a closer look at the water cycle and see what it has to do with clouds that appear and disappear. We will follow a drop of water in the ocean as it goes through the water cycle.

The drop of water is on the surface of the ocean, and as the sunlight warms the water, the drop of water evaporates. Now the water has entered the air as water vapour. It is no longer a liquid. As water vapour, it moves about in the air, and eventually condenses around tiny dust particles to form a cloud. The cloud is blown about by the winds until it meets cold air. When this happens the cloud falls as rain, back into the ocean. Our drop of water has completed the water cycle. Often the water cycle takes a drop of water on a long journey. For example, a drop of water from the ocean evaporates and, as water vapour, is carried by a current of air over the land. It forms a cloud and then falls as rain on a mountain-side. The water flows down the mountain in a tiny rivulet that enters a brook, and the brook in turn enters a stream that flows into a river. The river may travel through hundreds of miles of land before it empties into the ocean.

The water cycle has taken the drop of water on a long trip from the ocean to the land and back to the ocean again.

Sometimes there are many little detours, or side trips, on the journey. The rain may soak into the ground when it falls. The roots of a plant take in the water from the ground, and soon the water reaches the plant's leaves. There it evaporates and enters the air as water vapour. On a cool evening the water vapour may condense as dew on a blade of grass, and in the morning it may once again evaporate when the warm sunlight strikes the grass. These are but a few examples of the changes that are taking place all the time as part of the water cycle.

Water ordinarily flows downhill, but water can also move upward, and without being pumped. Try the following

**How does water get to the tops of trees?**

easy experiment. Put a drinking straw in a glass of water. A little ink or food coloring will make the water easier to watch. The water rises in the straw above the level of the water in the glass. Scientists call this rising of water in a straw or any narrow tube *capillary action*. Capillary action is a very important feature of water. It is what makes water rise to the top of tall trees. How does this work? When the straw is first placed in the water, the molecules of water are attracted by the molecules of the straw directly above them. The attraction between the water molecules and the straw is greater than the attraction between the water molecules them-



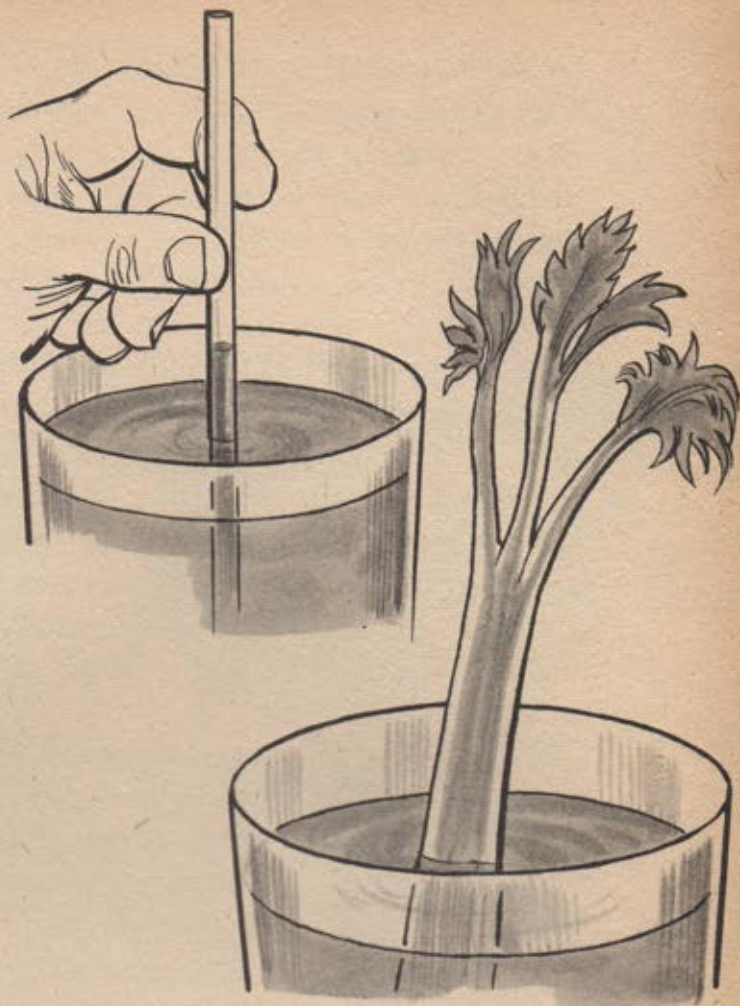
selves. Therefore, the water molecules are pulled upward. Since the water molecules cling together, when some of them are pulled upward they pull others with them. Thus, the water in the straw rises upward. It continues to rise until the weight of the water in the straw is equal to the force of the upward pull. In the stems of plants and the trunks of trees there are thousands of tiny tubes. Water in the soil rises through these tubes by capillary action.

For this experiment you will need a stalk of celery, a glass of water, and some red ink or red food colouring. Put several drops of the ink or

**How can you demonstrate capillary action in plants?**

food colouring in the glass of water. Cut the bottom end of the celery stalk so that the cut is fresh when you put it in the water. Now leave the celery in the glass for two or three hours. Take it out and examine it carefully. You can see by the red colour how high in the stalk the water rose. Cut across the stalk near the bottom and look at the slice. You will see little dots of red. These are the ends of tiny tubes that go from the bottom of the celery to the top. If you cut the stalk lengthwise you will see these little tubes with red water inside. Florists make use of capillary action to colour white flowers green for St. Patrick's Day. The green colouring rises through the stems and finally reaches the petals, turning them green.

Capillary action is what makes a blotter work. A blotter is a mat made of fibres pressed together. The spaces



Capillary action causes the water to rise in the straw above the water level in the glass, and makes the coloured water rise through the stalk of celery.

between the fibres act like tiny tubes. When a blotter is placed on a wet surface the liquid rises in the tiny spaces of the blotter by capillary action.

Because air has weight, pressure is exerted on everything within the atmosphere. At sea level the pressure is nearly 15 pounds

**What is atmospheric pressure?**

on every square inch of the earth's surface. Suppose you could weigh a column of air that covers one square inch of the earth's surface at sea level and



reaches to the top of the exosphere 600 miles above sea level. You would find that the column of air weighs nearly 15 pounds.

Since the pressure of the air is due to its weight, you can see that the higher you go in the atmosphere, the less the air pressure will be. As you go higher, less air will be above you to weigh down upon you. Six miles above the earth's surface, the pressure of the air is only four pounds on every square inch. At ten miles, the column of air above every square inch weighs only two pounds; at 100 miles, only two billionths of a pound.

The air not only presses downward, but presses equally in all directions. The total air pressure on the whole body of a human being is equal to several tons. Why doesn't so much air pressure crush our bodies? Because the process of breathing creates an air pressure inside the body that balances that outside it. As a result, we feel no pressure at all.

Fill a small drinking glass to the brim with water. Do this slowly and carefully, so that you can see the surface of the water bulge slightly over the top of the glass. Press a flat piece of cardboard on top of the glass. Press the palm of your hand on top of the cardboard and grasp the glass with the other hand. Turn the glass upside down quickly so that no water spills. Remove your hand from beneath the cardboard. The cardboard will remain in place, holding the water in the glass. The weight of the water cannot push the cardboard down

**How can you show that air exerts pressure?**



Perform this experiment over the kitchen sink. If your glass is not small enough, the weight of the water may be greater than the air pressure, and the water might spill out of the glass.

because air pressure is pushing upward on the cardboard, and the air pressure is greater than the weight of the water.

In 1654, a German scientist, Otto von

**What was von Guericke's experiment?**

Guericke, amazed everyone by showing how strong atmospheric pressure

is. He used two hemispheres, each of which was about twenty-two inches in diameter. Their rims were ground smooth and covered with grease, so that they would fit together tightly and allow no air to pass between them. Von Guericke put the rims together and, with an air pump he had invented, removed the air inside the hollow sphere. So great was the air pressure on the outside (more than thirteen tons) that it took sixteen horses, eight on each side, to pull the hemispheres apart.

You can perform an experiment like that of von Guericke. You will need two plungers of the kind that are used to force water through drains. You will also need a friend to help you. Thoroughly wet both plungers. Ask your friend to sit in a chair and hold the



plunger handle between his knees, the rubber cup upward. Place the cup of your plunger upon the other one, and slowly and carefully push down until most of the air has been expelled from the plunger cups. Now, each of you grasp a handle, and see how difficult it is to pull the plungers apart.

If you have only one plunger, place it on a smooth wet surface and push down hard. You will see how hard it is to pull it free. All the force holding the plunger to the surface is due to atmospheric pressure.

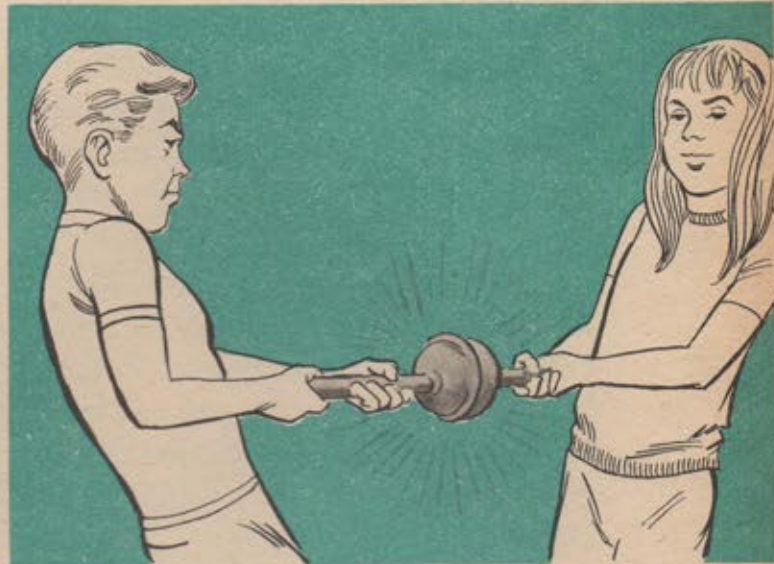
We learned that a column of air one inch square and 600 miles high weighs 15 pounds. Suppose we could put this column of air on one side of a scale and a column of mercury one inch square on the other side of the scale. To balance the air, the mercury would have to be 30 inches high. The fact that a 30-inch column of mercury weighs as much as

**How do we measure atmospheric pressure?**

inch square and 600 miles high weighs 15 pounds.

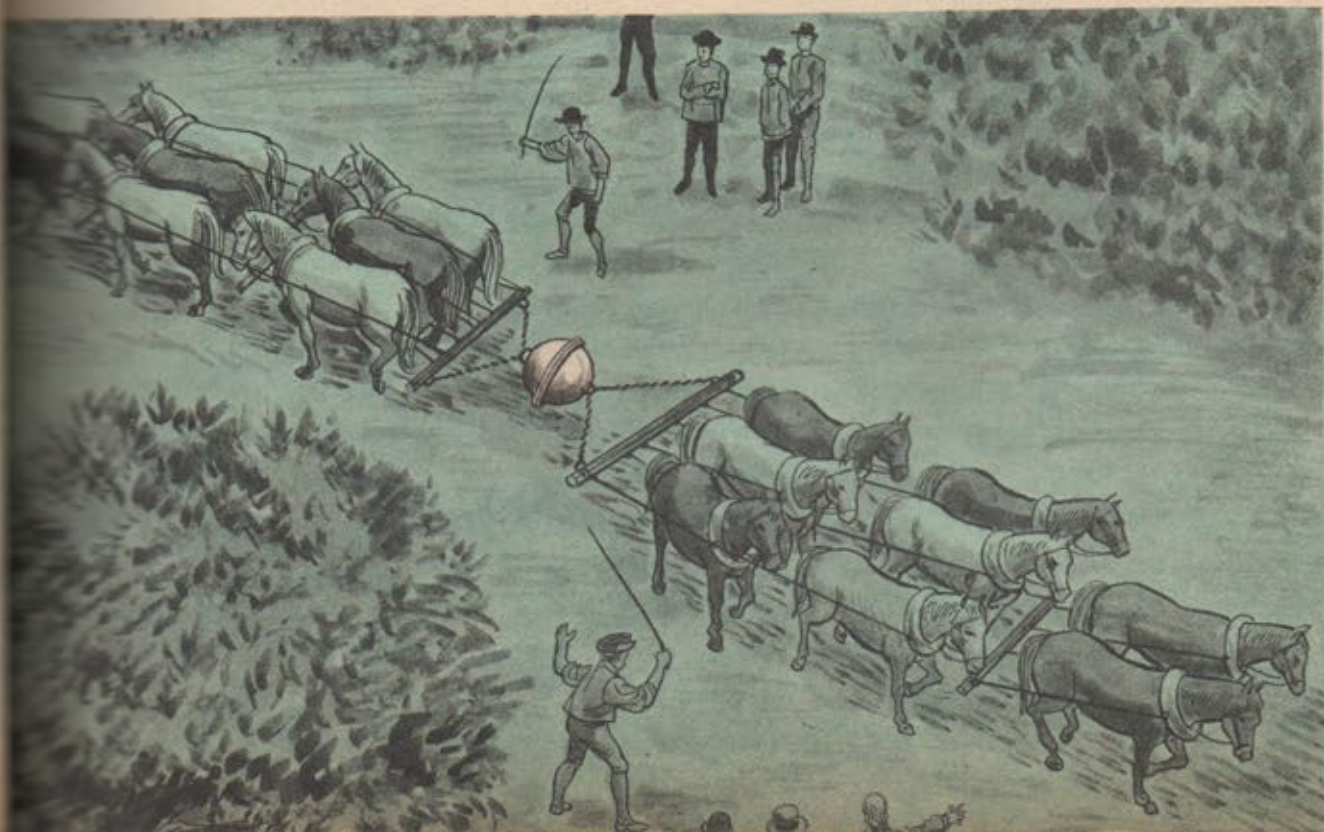
a 600-mile column of air can be used to measure atmospheric pressure.

If you were to fill a glass tube more than 30 inches long with mercury and place it upside down in a dish of mercury, some of the mercury in the tube



You can perform an experiment similar to von Guericke's. For the spheres substitute two plungers and for the sixteen horses, yourself and a friend.

Sixteen horses could not pull von Guericke's steel spheres apart.





would run out until the weight of the mercury left in the tube is balanced by the weight of the air pressing on the mercury in the dish. No air would be pressing on the mercury in the tube because the space above it is completely empty. This arrangement of glass tube and mercury is called a *mercury barometer*.

Let us suppose that we are carrying a mercury barometer from sea level up a mountain. When we begin our ascent, the mercury column measures 30 inches. When we have climbed 940 feet, the mercury column is only 29 inches high. When we have climbed to 8,360 feet — a little more than one and a half miles above sea level — we find that the column of mercury is only 22 inches high.

Why does the column of mercury become shorter as we carry the barometer higher? Because the column of air that balances the mercury becomes shorter and lighter as we go higher. We know that at sea level the column of air weighs nearly 15 pounds. At 8,360 feet above sea level the column of air weighs almost 11 pounds and is balanced by a 22-inch column of mercury that also weighs almost 11 pounds.

Thus, when we measure the height of a column of mercury in a glass tube, we are also measuring the pressure of the column of air above the mercury. We usually express the pressure in units of height of the mercury column. We say, for example, that the atmospheric pressure at the top of the Empire State Building is "29 inches of mercury," or simply, "29 inches."

Another kind of barometer is the



*aneroid* barometer. The word "aneroid" means "without liquid." This barometer does not contain any mercury. The main part of an aneroid barometer is an airtight can from which as much air as possible has been pumped. A spring attached to the top of the can keeps the can from collapsing under pressure of the outside air. A pointer is attached by levers and a chain to the top of the can, and is arranged so that it points to a scale divided into inches.

When the air pressure increases, it pushes the top of the can down a little, and the pointer moves toward the higher numbers on the scale. When the air pressure decreases, the spring pushes the top of the can up, and this move-

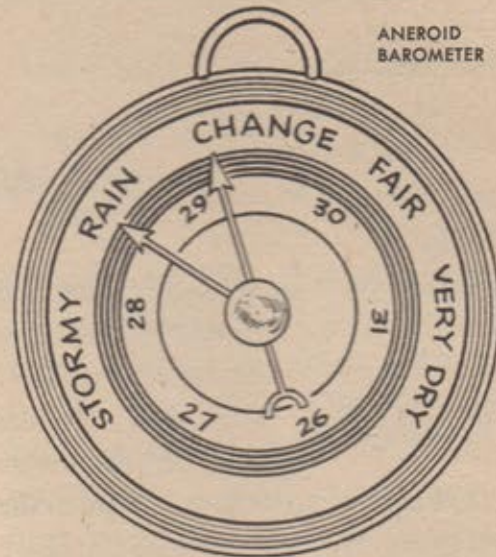




In the middle of the seventeenth century Italian mathematician and physicist Evangelista Torricelli discovered the principle of the barometer, and thereby discovered the force of atmospheric pressure. He calculated that in order to support a column of mercury about thirty inches high, the atmosphere had to press downward with a weight of nearly fifteen pounds per square inch.

About the same time Otto von Guericke of Magdeburg began investigating air pressure. Out of his work came the water barometer. A brass tube that was over thirty-four feet long, with a closed glass section at one end, was filled with water. Von Guericke then inverted the tube, placing the open end in a tub of water. As the pressure of the atmosphere changed the water in the tube rose and fell.

ANEROID  
BAROMETER



MERCURY  
BAROMETER



ment, too, is measured on the scale by the pointer, which moves toward the lower numbers.

We learned that a barometer at 8,360 feet will measure 22 inches of mercury. Therefore, if we have a barometer that measures 22 inches, we know we are 8,360 feet above sea level. Thus we can use a barometer to measure altitude. Many aeroplanes use special barometers, called altimeters, to measure the plane's altitude.

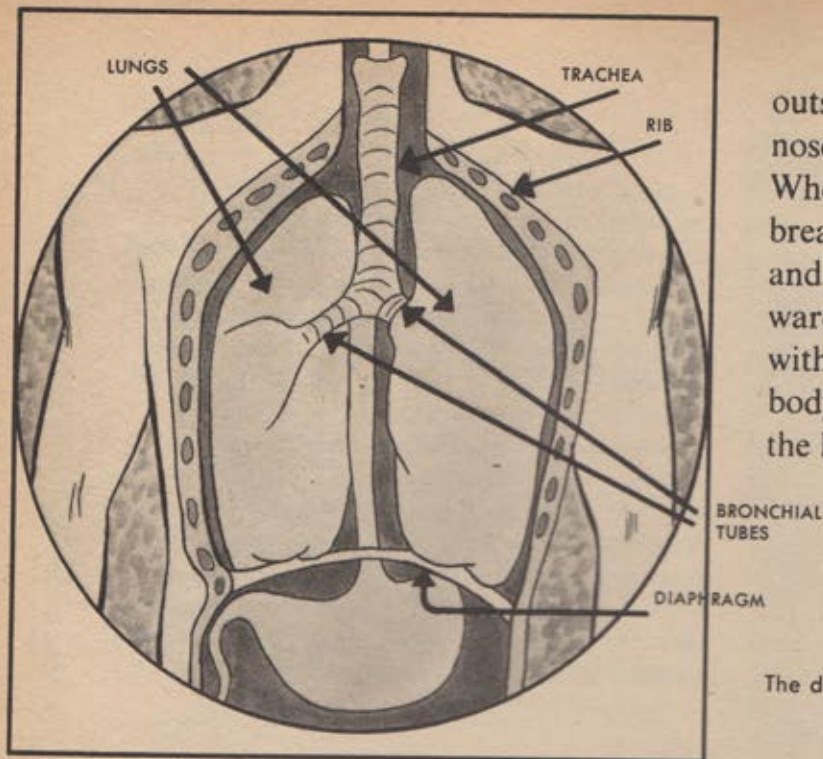
You know that human beings must breathe in order to live. Breathing is so natural that hardly anyone stops to ask just

**How does air get into our lungs?**

how we breathe. Let us see how this very important activity takes place.

Stretching across the entire body cavity beneath the lungs is a large flat muscle called the *diaphragm* (dy'-uh-fram). When you inhale, or take a breath, the diaphragm moves downward and the ribs move upward and outward. This increases the size of the body cavity. As a result there is less air pressure within the body cavity than outside the body. Atmospheric pressure





outside the body pushes air through the nose or mouth and down into the lungs. When you exhale, or blow out your breath, the diaphragm moves upward and the ribs move downward and inward. This results in more pressure within the body cavity than outside the body. This pressure pushes air out of the lungs through the nose or mouth.

The diagram at left shows you how we breathe.

## Air and Water at Work

Perhaps you have seen your mother use an egg timer when she boils an egg.

**How did ancient man use water to measure time?**

The sand in one end of the tube

runs through a tiny opening into the lower end of the tube in exactly three minutes. When all the sand is in the lower end of the tube, your mother knows that the egg has boiled for three minutes. An egg timer is very much like a device the ancient Greeks used to measure time. The Greeks let water drip slowly from a jar with a tiny hole in it. When all the water had dropped out the Greeks knew that a certain amount of time had gone by. They used this "water clock," called a *clepsydra* (klep'-si-dra), to measure the length of speeches in the law courts. A speaker

had to end his speech when the jar was empty.

There were several other kinds of water clocks. One was very similar to the one we just described except that the jar was made of glass and there were markings on the side of it. The marks were arranged so that each one stood for an hour. As the water dripped out of the jar, the water level became lower, marking the hours as they passed. Some water clocks had a floating figure of a woman whose arm pointed to the hour marked on the side of the jar.

In another kind of water clock, the water from the container dripped into a cylinder. In the cylinder was a floating piston with a long shaft on top of it. Cut into the shaft were gear teeth. These teeth fitted into a circular gear.



As the piston floated upward, the teeth on the shaft moved the circular gear. A pointer attached to the circular gear moved slowly around in a circle, pointing to numbers on a dial outside the gear. When the piston was at the bottom of the cylinder, the pointer pointed to 24, which indicated midnight. As water dripped into the cylinder and filled it little by little, the cylinder floated slowly upward. As the piston moved upward, its gear teeth turned the circular gear, and the pointer pointed to the hours as they passed, beginning with the numeral one. In 24 hours the cylinder had filled, and the pointer had turned once around the dial. At the end of 24 hours, the water clock had to be set by emptying the cylinder.

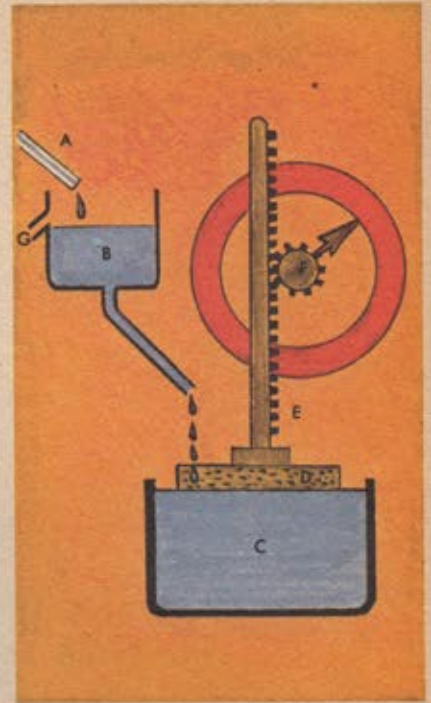


In the Greek clepsydra, the water dripped out of the vessel.



In the Chinese and Indian waterclocks a small brass bowl with its bottom pierced was floated on a basin of water. The floating bowl gradually filled with water, and, after a measured interval of time, sank. An attendant then struck a gong and set the bowl afloat again.

Water is supplied continuously from pipe A into reservoir B, from where it slowly drips into tank C. An overflow tube G keeps the level in the reservoir constant. As the level of water in tank C rises, rack E is pushed up by float D. The rack turns geared wheel F, and the hand of the clock moves the dial to indicate the hour.



Ever since ancient times man has used the force of moving air and water to work for him. Wind is made to do work by turning the sails of windmills. The famous windmills of the Netherlands and Belgium had huge cloth sails, some of which were two stories high. Each windmill had four sails set in the shape of a cross and attached to a shaft. The sails did not face the wind directly, but were turned at a slight angle to the direction from which the wind was blowing. When the

**How do windmills work?**

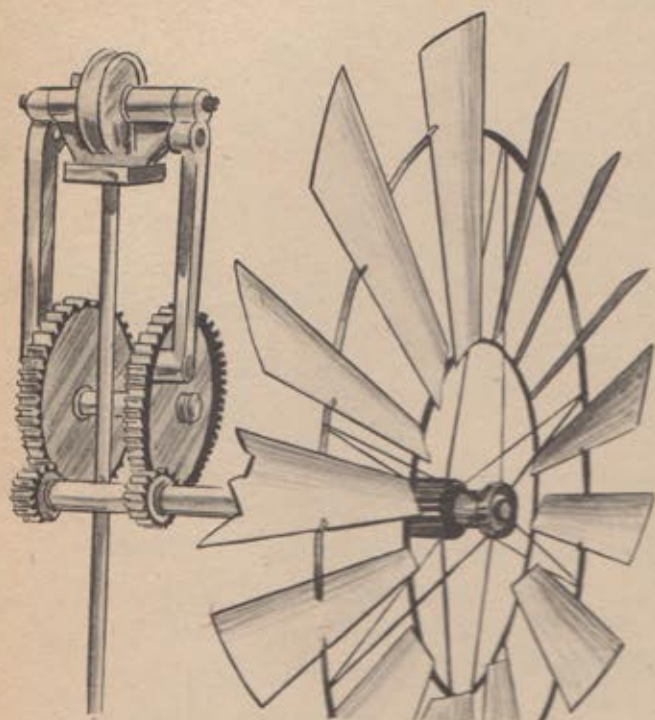


wind struck the sail, the moving air slipped past it. Because the sail was turned slightly sidewise, it was pushed in a direction crosswise to that in which

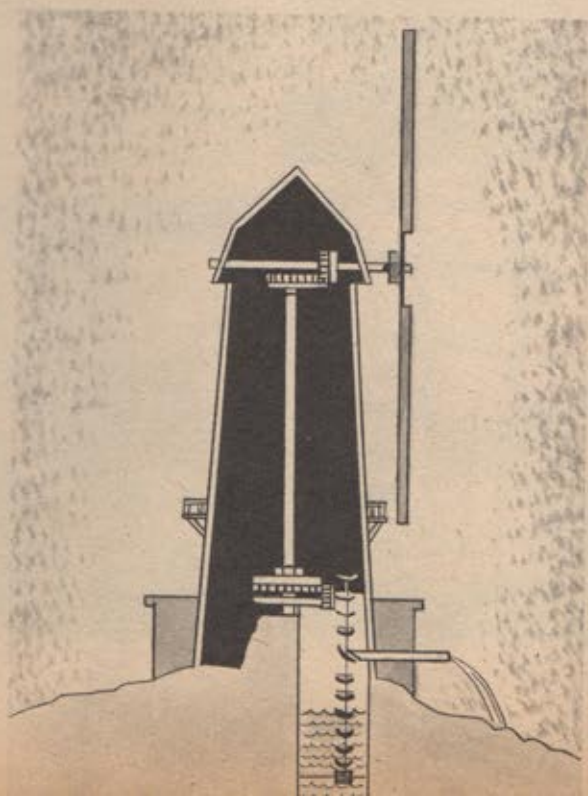
the wind was blowing. As a result, the sail turned the shaft. The shaft was attached to grindstones or to a pump. When a stiff wind blew against the sails, the windmill ground grain or pumped water.

Almost all the old windmills have been replaced by modern ones that have steel blades instead of cloth sails. Two to sixteen of these blades are set on a shaft at scientifically measured angles, so that the blades spin rapidly even in a slow wind. Because these blades work so much better, they need not be as large as the old cloth sails. Very few modern windmills have blades longer than a man is tall.

Steel windmills are used in many parts of the world, and their main uses are to produce electricity and to pump water for irrigating crops. To produce electricity, the shaft of the windmill is attached to a dynamo. People who live far from a large electric generating



Left, windmill with canvas sails, below, cutaway of a windmill used to pump water out of the fields.





plant may have their own windmills on a tall steel tower. The windmill produces electricity for lighting homes and running household appliances. To pump water for irrigation, the electricity may run the motor of a water pump. Or, the windmill may be connected directly to the shaft of the pump.

To make water do work for him, man

**How do water wheels work?** invented the water wheel. One of the earliest types of water

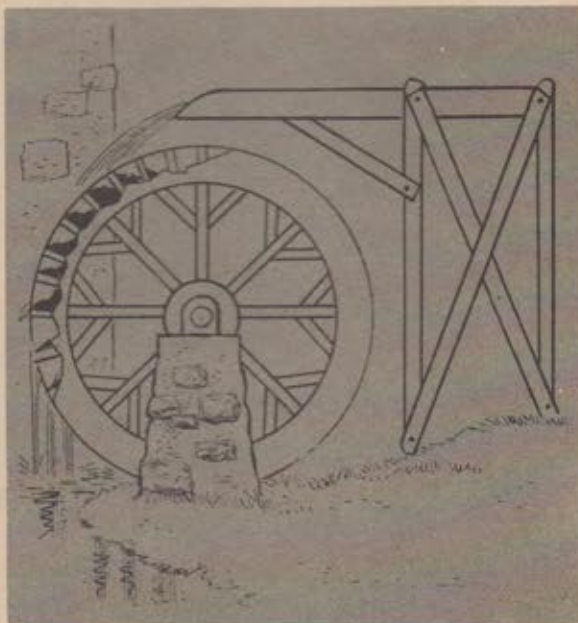
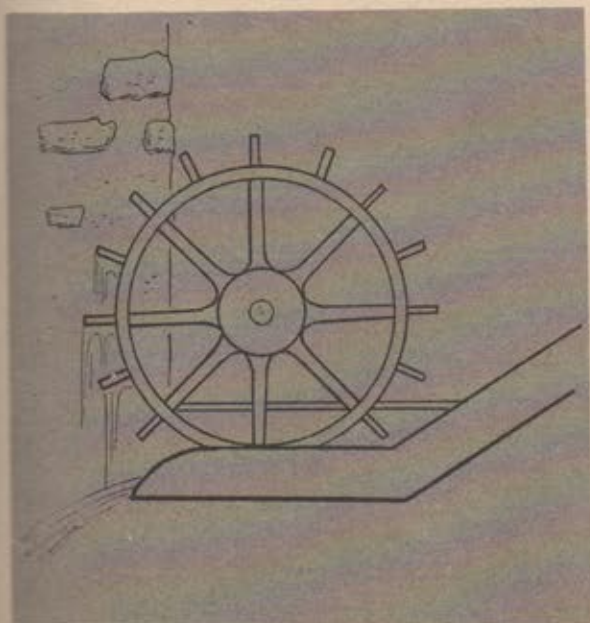
wheels consisted of two discs of wood set a foot or two apart at one end of a round shaft. In the space between the discs were several flat pieces of wood, called paddles. These paddles were attached to both the shaft and the discs and were long enough to stick out past the rims of the discs.

The wheel was placed on a wooden framework over a stream at just the height to allow the lowermost paddle to reach beneath the surface of the water.

The water pushed against the paddle, moving it in the direction the stream was flowing, and caused the wheel to turn a little. As one paddle turned up and out of the water, the next paddle dipped beneath the water and was pushed forward by the stream. Thus the wheel kept turning. The turning shaft was made to do work, perhaps by attaching it to a grindstone to grind corn or wheat.

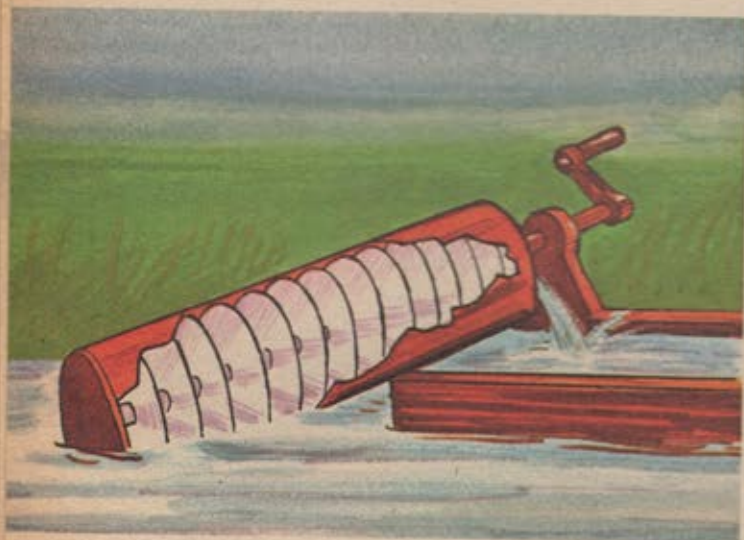
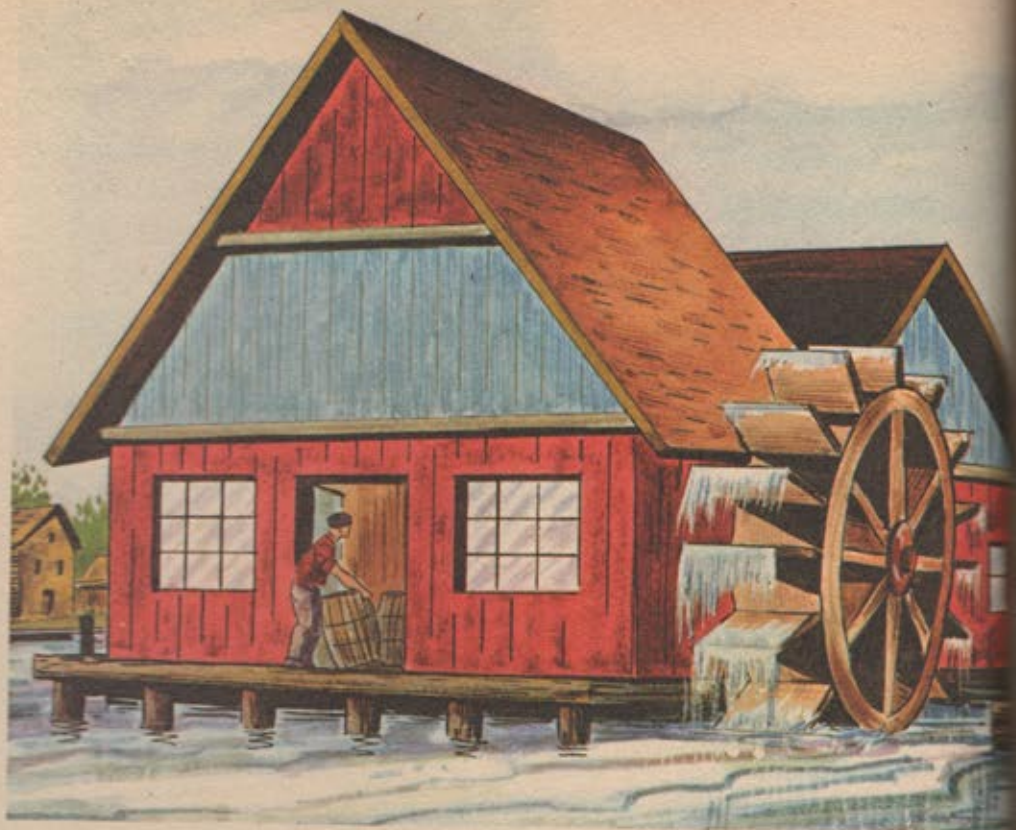
A very clever kind of water wheel was called *Archimedes' screw*, after Archimedes, a Greek mathematician and scientist, who lived in the city of Syracuse on the island of Sicily about 2,300 years ago. Archimedes' screw had two main parts: a large, hollow, wooden cylinder, and a water wheel. The wheel was built around the wooden cylinder close to one end. Inside the cylinder was a wooden spiral that ran the whole length of the cylinder, like the grooves on a screw. The end of the cylinder, with the water wheel attached, rested

Left, a water wheel is said to be undershot when water turns the wheel by striking its blades from the bottom. It is called an overshot water wheel, at right, when it is turned by water falling upon the paddles from above.





Water mill driven by undershot wheel.



Cutaway view of Archimedes' screw.

on a support set on the bottom of the river. The other end reached to the river bank. The cylinder was tilted slightly upward toward the shore. When the stream turned the water wheel, the lower end of the spiral scooped up water and moved it upward along the spiral

until it ran out of the upper end of the cylinder. This was the way water was transported to irrigate crops.

Obtain a straight knitting needle.

How can you make a water wheel?

Push the needle through the centre of a cork.

Push half a dozen steel penpoints into the cork at evenly spaced intervals circling around the cork. Bend a heavy piece of wire (a wire clothes hanger will do) into the shape shown in the illustration. Rest the knitting needle on the wire frame you have just made.

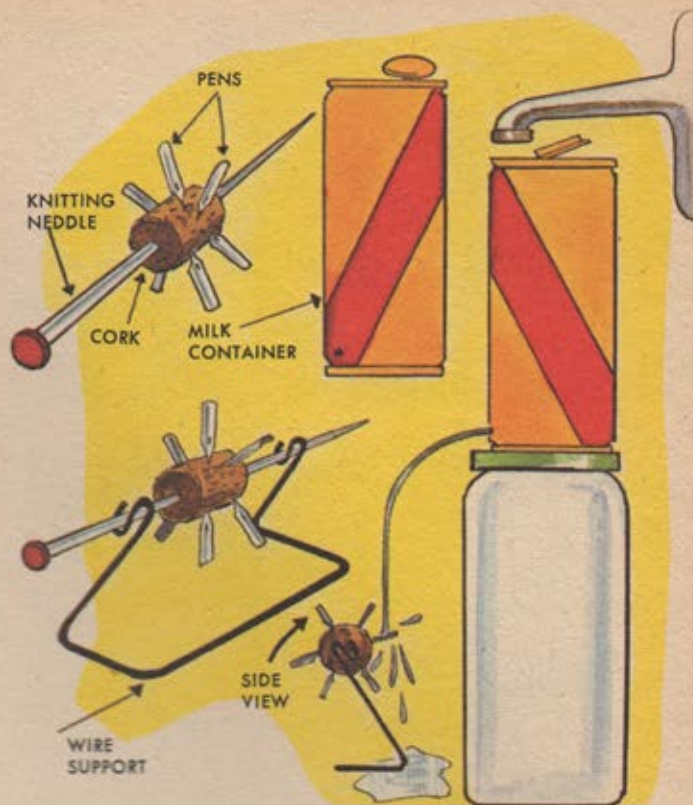
Using a pencil poke a hole in the centre of one side of a milk carton. Place the carton in a sink so that water from a faucet will run into the hole in the top of the carton. When a stream of water begins to pour out of the hole in the side of the carton, place the wire



frame beneath it, so that the stream strikes the penpoints. Your water wheel will spin rapidly.

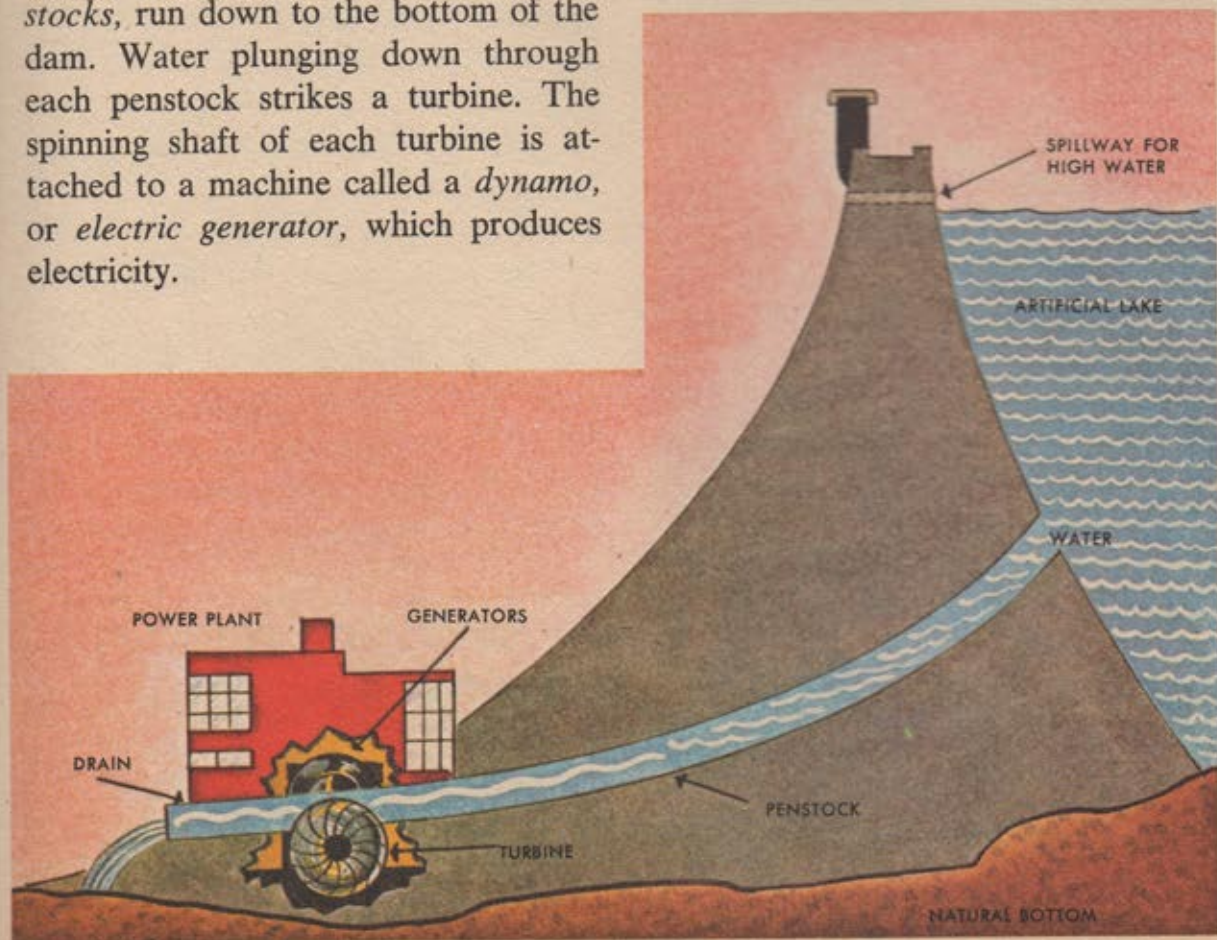
Modern water wheels are made of metal and are called *water turbines*. The main use of water turbines is to produce electricity. In mountainous country, streams run down the sides of mountains very swiftly. Some of the water from these streams is sent through pipes. At the end of the pipes are turbines that turn very rapidly when the swiftly moving water strikes them.

In flat country, water may be given the force needed to turn turbines rapidly by storing the water behind high dams. About halfway down from the top of the dam are openings that lead to long, wide pipes. These pipes, called *penstocks*, run down to the bottom of the dam. Water plunging down through each penstock strikes a turbine. The spinning shaft of each turbine is attached to a machine called a *dynamo*, or *electric generator*, which produces electricity.

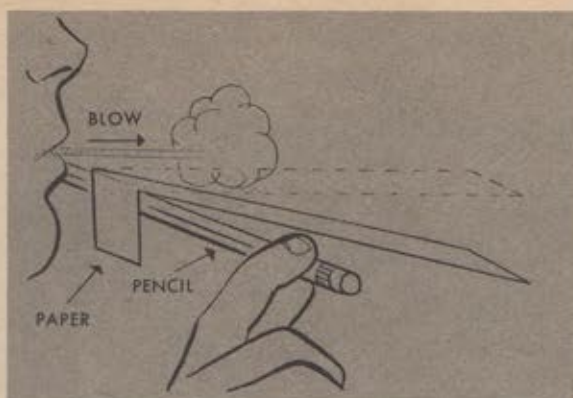
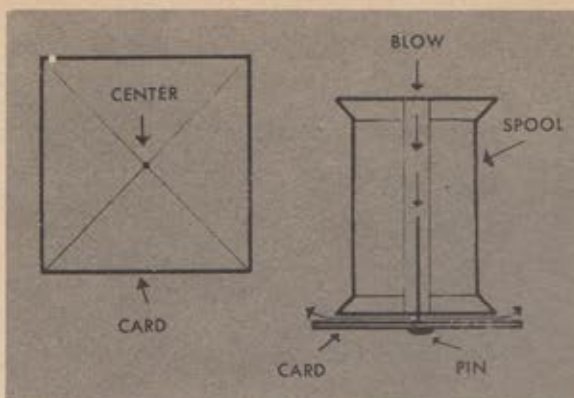


How to make your own water wheel.

Water is put to work to help create electricity.







Take a small card, push a pin through its centre, and put the pin into the hole of a spool. Hold the spool so that the hole through it is vertical and hold the card against the spool. Now blow through the hole in the spool, at the same time releasing your hold on the card. You might expect the card to be blown away from the spool. However, you will find that as long as you blow through the spool the card will remain near the spool. As soon as you stop blowing, the card will fall. What holds the card up when your breath is passing through the hole in the spool? Some force stronger than gravity must be holding the card up.

Let us see this same force at work again. Curl one end of a sheet of paper around a pencil. Hold the pencil near your lips and blow your breath across the paper. The paper will rise, and will remain extended in the air as long as you continue to blow.

Both of these experiments illustrate a scientific principle that was discovered by a Swiss mathematician and physicist, Daniel Bernoulli, who lived more than 200 years ago. Bernoulli discovered that when the speed of a fluid is high, the pressure of the fluid is low;

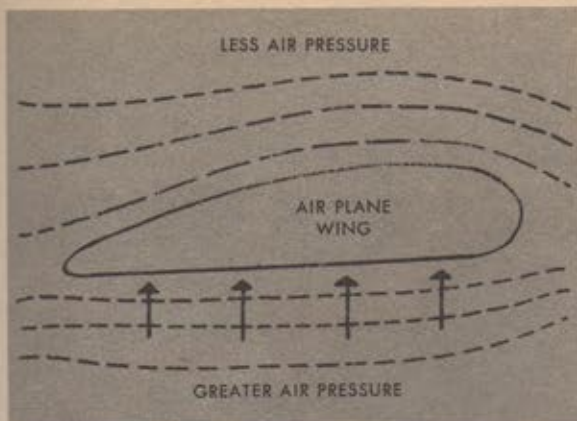
when the speed is low, the pressure is high. Remember that air is a fluid. When you blew through the hole in the spool, your breath — which is air — moved swiftly across the upper surface of the card and reduced the atmospheric pressure on that surface. The atmospheric pressure on the lower surface remained unchanged. Since the pressure pushing upward on the card was greater than the pressure pushing downward, the card stayed up. Likewise, your breath moving swiftly across the sheet of paper lowered the pressure on its upper surface, and the greater pressure on the lower surface pushed the paper up.

Have you ever noticed how a shower curtain moves in toward the spray of water? The water squirting outward from the shower's nozzle moves air along with it. The swiftly moving air decreases the pressure on the inside of the shower curtain and the pressure of the outside air pushes the curtain inward.

An aeroplane wing is flat on the bottom and curved on top.

**What holds an aeroplane up?** As the plane moves through the air, the air flowing over the top of the wing moves faster than the air flowing along





the bottom. The air that flows over the top of the wing must pass over the curve in the same length of time as air beneath the wing passes along the straight undersurface. Since a curved line is longer than a straight line between the same two points, the air moving the longer distance must move faster than the air moving the shorter distance. Therefore, air moves faster over the upper surface of an aeroplane wing than over the lower surface. According to Bernoulli's Principle, the pressure on the upper side of the wing is less than the pressure on the underside of the wing. Thus, the higher pressure of the air beneath an aeroplane's wings holds it up.

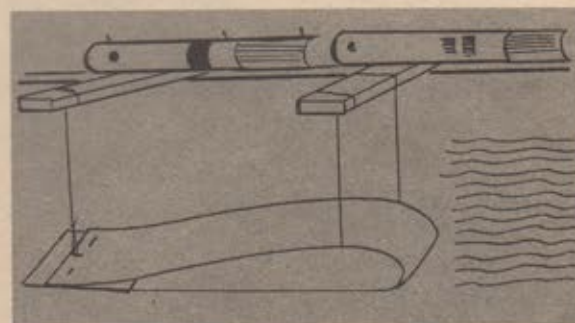
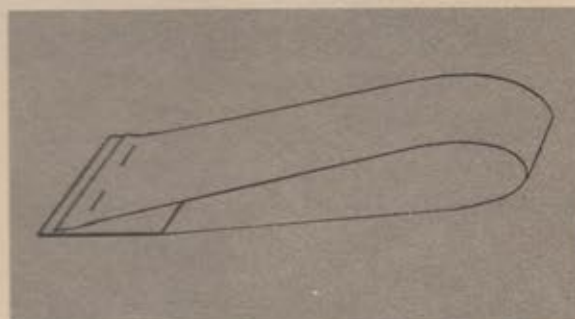
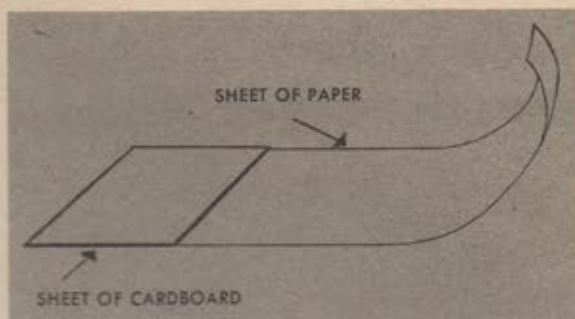
For this experiment you will need a piece

**How can you show why its wings will lift an aeroplane?**

of cardboard and a sheet of paper the same width. Cut the cardboard so that it is about half as long as the paper. Now staple or glue the cardboard to the sheet of paper as shown in the illustration. Bend the paper back over the cardboard and staple it about one inch from the end of the cardboard. The upper surface of the paper will be curved, the lower one will

be straight. The paper has the general shape of a section cut from an aeroplane wing. The rounded end is the forward end.

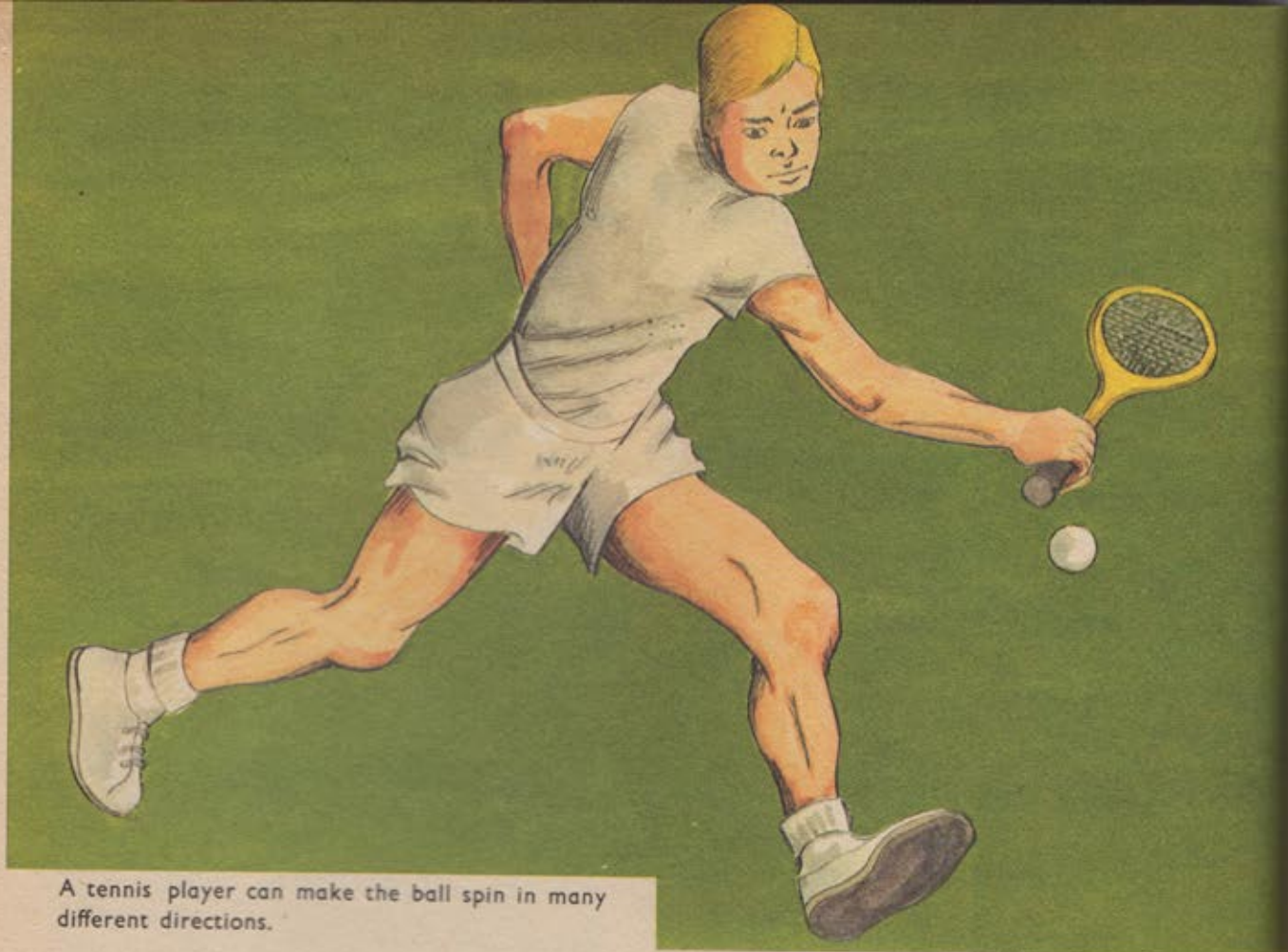
Suspend the paper by three pieces of string, two passed through the forward end and one through the rear part of the folded paper. Attach the strings to sticks, as shown in the illustration, or



Experiment that shows why its wing lifts an aeroplane.

use four piles of books to hold the ends of the strings. Place an electric fan in front of the "aeroplane wing" and turn the fan on. The wing will rise slightly as the moving air lowers the pressure on its upper surface and the air beneath provides lift.





A tennis player can make the ball spin in many different directions.

A tennis player can deceive his opponent by making the ball spin so that its path curves upwards, travelling further than expected, or downwards, dropping short. He can make it swerve either way to the right or to the left. To make it swerve downwards he draws the racquet up at the moment of impact so that as the ball moves away it is spinning in the air in the same way as if it were rolling along the ground away from him. Below the ball the speed with which the air appears to be moving past it is increased by the effect of the air dragged round with it as it spins; above the ball this speed is reduced. Where air is moving fast the pressure

**How does a tennis player make the ball spin?**

opponent by making the ball spin so that its path

is lower than where it is moving slowly, so the pressure below the ball is less than that above it, and a downward force acts on it.

A right-handed player, by drawing the racquet towards him at the moment of impact, can slice the ball to make it spin about a vertical axis and so swerve to the right for a forehand shot or to the left for a backhand shot.

A siphon is a tube shaped something like the letter "J" upside down. With it you can make water flow up over the wall of a container, without lifting the water by pumping. For this experiment you will need a rubber or plastic tube about three feet long, a pail of water, and an

**How can you make a siphon?**

like the letter "J" upside down. With it you can make



empty pail. Place the pail of water on a table and put the empty pail on the floor next to the table. Fill the tube completely with water. You can do this by dropping it into the pail of water or by filling it with water from the faucet. Now pinch both ends of the tube so that no water can escape, and quickly place one end of the tube in the pail of water well below the water's surface. Let the other end hang down into the empty pail. Let go of both ends of the tube at the same time. The water will flow through the tube, up over the side of the pail on the table, and down into the lower pail. If you keep the upper end of the tube close to the bottom of the pail on the table, all the water will soon be in the pail on the floor.

A siphon is very useful for emptying an aquarium or even for taking the water from a wash bowl that has a stopped-up drain. Chemists use siphons in laboratories to transfer liquids from one bottle to another. Let us see how this simple, but very useful, device works.

When you removed your finger from the lower end of the tube, some water flowed out, leaving an empty space behind it. You remember that the atmosphere is pressing on all things on the surface of the earth. The atmospheric pressure on the surface of the water in the pail pushed water up the tube to fill the empty space there. More water flowed out, and was again replaced, due to atmospheric pressure. This process continued until all the water flowed through the tube and

emptied the pail. You may wonder why atmospheric pressure did not keep water from flowing out of the lower end of the tube. It is because the weight of the column of water in the tube caused a downward force greater than the upward force of the atmospheric pressure.

Archimedes the Greek scientist who lived about 2,300 years ago, was a kinsman of King

**How did Archimedes solve the problem of King Hiero's crown?**

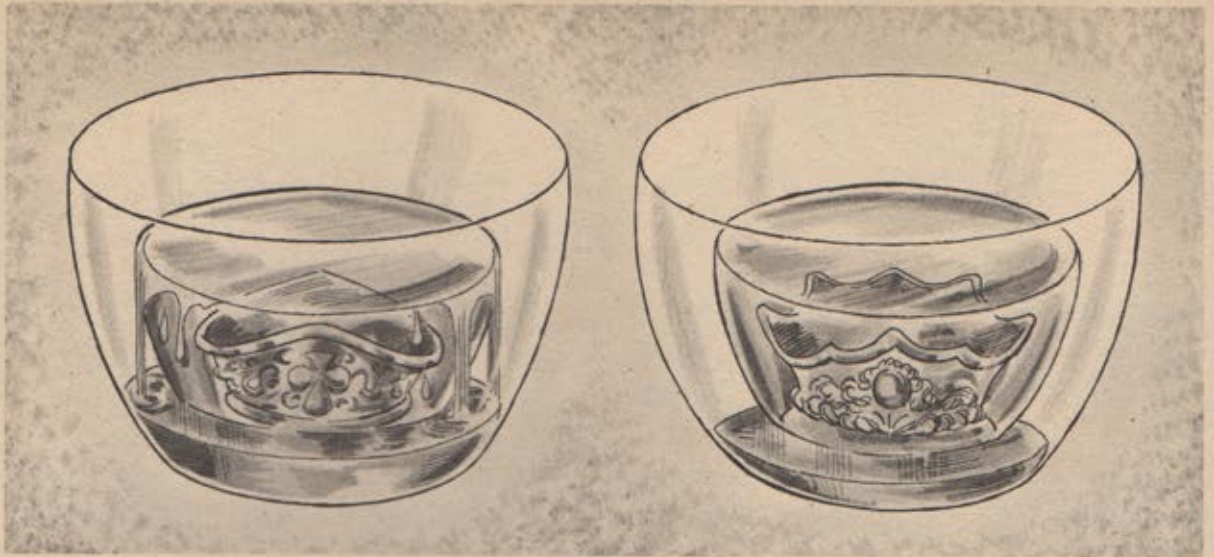
lived about 2,300 years ago, was a kinsman of King

Hiero, the ruler of Syracuse. According to legend, one day in the year 250 B.C., the king bought a crown that he suspected was made of gold mixed with silver. Gold is more expensive than silver, so if King Hiero had paid for a



How to make your own siphon.





Both crowns weighed the same, but since more water spilled from the bowl in which the new crown was immersed, Archimedes concluded that the new crown was larger and, therefore, could not be pure gold.

pure gold crown, he had been cheated. The king asked Archimedes to find a way to tell whether the crown really did have silver in it. Archimedes knew that silver weighs less than gold, so it should have been easy to tell whether the new crown had silver mixed in the gold. Archimedes had only to weigh the new crown and another crown the same size made of pure gold. If the new crown were made of gold mixed with silver, it would weigh less than a pure gold crown of the same size. But the king's problem was not this easy to solve. Archimedes found that the new crown weighed the same as a pure gold crown that appeared to be the same size. But he couldn't be sure the crowns were really the same size because they were both elaborately carved and it was not possible to measure them accurately. He would have to find a way to measure the crowns. If the new crown had silver in it, it would have to be larger than the crown of pure gold, since they both weighed the same.

While Archimedes was thinking about this problem, he went to the public baths of Syracuse. As he sat down in his bath, he watched the water spill over the sides of the tub. This sight gave him the idea he needed to solve the king's problem. Archimedes was supposedly so excited at finding the answer that he jumped out of the bath and ran naked through the streets shouting, "Heureka! Heureka!" which is Greek for, "I have found it! I have found it!"

Archimedes went to King Hiero and told him he could solve the problem of the new crown. He asked the king to send for the crowns and for two bowls of equal size and large enough to contain the crowns. He also asked for two larger bowls in which he placed the smaller bowls. He then filled the two small bowls to the brim with water, and placed a crown in each bowl. Water spilled over the sides of both bowls into the larger bowls. Archimedes carefully measured the amount of water that



spilled from each bowl. He found that more water spilled from the bowl in which he had put the new crown. This meant that the new crown was larger than the crown of pure gold. Since the crowns weighed the same, Archimedes knew that the new crown, being larger, must be made of a lighter metal than gold. The king was right; as he suspected, the new crown was not pure gold.

When Archimedes was sitting in his bath, he noticed something else:

**What is Archimedes Principle?**

his body was lighter than it would have been had there been no water in the bathtub. You probably have noticed the same thing when sitting in a bathtub. Archimedes understood that he weighed less when in the water because some of the water was pushing upward on his body. This upward-pushing force is called a *buoyant force*. Archimedes, being a mathematician, wanted to know how strong the buoyant force was. He found that the strength of the buoyant force on his body was equal to the weight of the water that spilled over the sides of the tub. This water spilled because Archimedes' body took up space in the tub that had been taken up by water before he had climbed into the tub. When an object takes up space in a liquid in this manner, we say that the object *displaces* the liquid. Archimedes' rule — or principle — is that *an object in a liquid is buoyed up by a force that is equal to the weight of the displaced liquid*.

When a buoyant force acts on an ob-

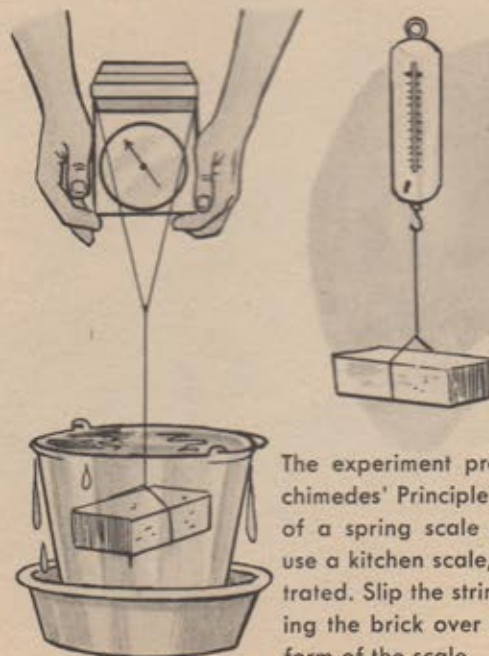
ject, the object weighs less. Because of Archimedes' Principle, we can tell how much less the object weighs. We can say Archimedes' Principle in another way: *the loss of weight of an object in a liquid is equal to the weight of the liquid displaced*.

To test Archimedes' Principle, you will need a bucket, a large pan, a spring scale, a brick, a large bottle, a funnel, and some string.

**How can you prove Archimedes' Principle?**

Place the bucket into the pan and fill the bucket to the brim with water. Do not spill any into the pan. If you accidentally spill some water, mop it up with a cloth. Tie the string securely around the brick so that you can hook it onto the spring scale. Hold the scale high enough so that the brick hangs free. Note the weight of the brick and mark it down on paper.

Slowly lower the brick into the water in the bucket. When the whole brick is



The experiment proves Archimedes' Principle. Instead of a spring scale you can use a kitchen scale, as illustrated. Slip the strings holding the brick over the platform of the scale.



beneath water, but not touching the bottom of the bucket, again note the weight of the brick on the scale. The brick will weigh less. Subtract the weight of the brick in the water from the weight of the brick in air. The difference will equal the amount of weight the brick lost when in water.

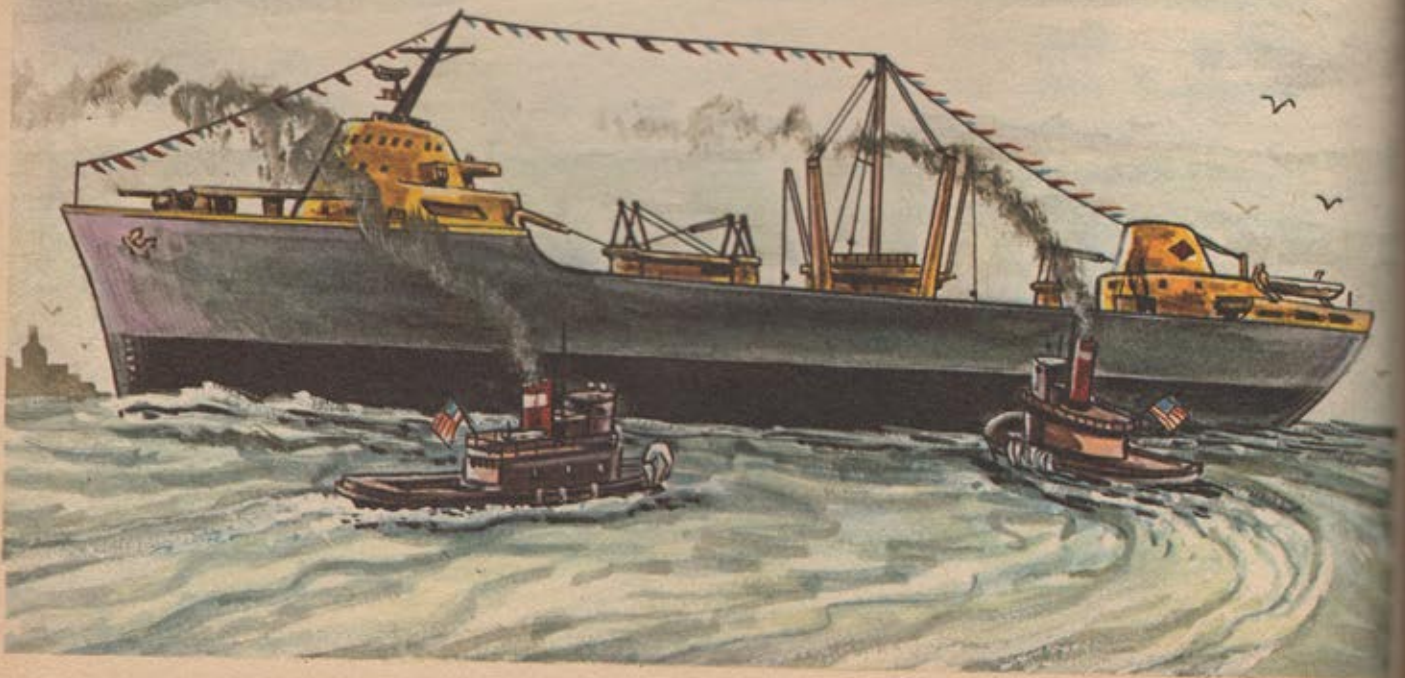
Remove the brick from the water. Take the bucket out of the pan, being careful not to spill any more water from the bucket into the pan. Weigh the bottle, then, using the funnel, carefully pour the water from the pan into the bottle. Weigh the bottle and the water together. Subtract the weight of the bottle from the weight of the bottle and water together. This will give the weight of the water displaced by the brick. If you have been careful, this weight will equal the amount of weight the brick lost when placed in water. This proves Archimedes' Principle which, as you

remember, says that the loss of weight of an object in a liquid is equal to the weight of the displaced liquid.

A battleship is made of steel and is extremely heavy. The British aircraft carrier *Ark Royal* weighs 50,786 tons when it is fully loaded. When we think of the fact that the steel of which it is constructed is so much heavier than water, it does not seem reasonable that objects as heavy as ships should float. Why, then, do steel ships float?

Archimedes' Principle will give us the answer. You remember that the buoyant force on an object in water is equal to the weight of the water displaced. If the weight of the water displaced is more than the weight of the object, the buoyant force will be greater

A steel ship floats because the part of the ship below the surface displaces a volume of water that weighs as much as the whole ship. The ship is buoyed up with a force equal to the weight of this displaced water.





than the weight of the object, and the object will float. The *Ark Royal* is 720 feet long, 166 feet wide, and the beam is 112.8 feet. The weight of the water displaced by the volume of this huge ship is more than 50,786 tons; therefore, the buoyant force acting on the ship is more than 50,786 tons. As a result, the great mass of steel floats. If some giant hand were to crush the *Ark Royal* into a solid lump of steel, it would displace a much smaller volume of water. The water displaced by the solid lump of steel would weigh less than 50,786 tons, therefore the buoyant force would be less than 50,786 tons and would not be enough to hold the steel up in the water.

Obtain a sheet of metal foil such as your mother uses in the kitchen. From the foil, make a boat about five inches long and two inches wide. If the boat does not leak, it will float in water. The water the boat displaces weighs the same as the metal foil; therefore, the buoyant force is equal to the weight of the foil. Roll the foil into a tight ball, squeeze the ball flat, and drop it into water. It will sink, because now the ball displaces water that weighs less than the foil, and as a result the buoyant force is too small to hold the foil up in the water.

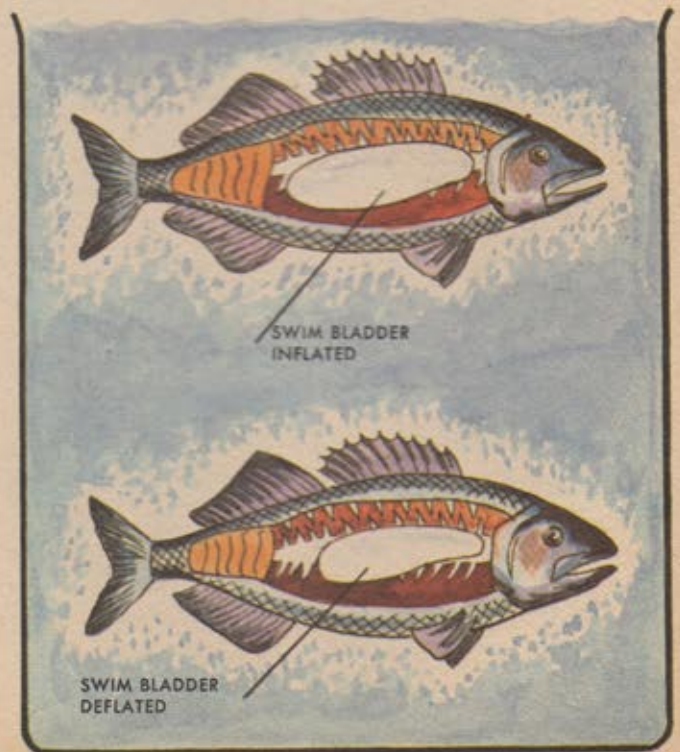
You have seen fish in an aquarium swimming up and down in the water and floating at whatever level they choose. How can a fish float in water near the surface and also near the bottom of the water? If

**How does a fish  
move up and down  
in the water?**

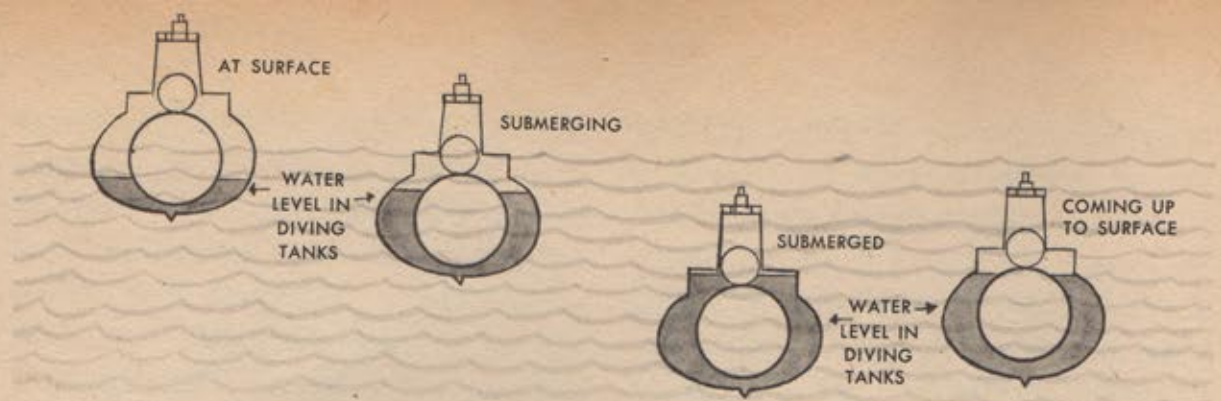
swimming up  
and down in  
the water and  
floating at

the buoyant force is great enough to keep the fish afloat near the surface, how can the fish overcome the buoyant force and remain near the bottom? Why doesn't the buoyant force always push the fish up near the surface whenever the fish swims deeper? The answer to these questions is that the fish has an organ called a *swim bladder* by means of which the fish can change its size. The swim bladder is a sac of elastic tissue between the stomach and the backbone. The bladder is filled with air and can be made larger and smaller. When the swim bladder is largest, the size of the fish is increased; this means that the fish displaces the most water that it can, and the buoyant force on the fish is greatest; as a result, the fish floats at the surface. When the fish makes its swim bladder small, the fish displaces less water, and the buoyant force upon it is less; as a result, the fish

When the swim bladder is inflated the fish displaces more water. This causes it to rise to the surface.







Schematic drawing that shows how the diving tanks in a submarine function. By filling or emptying the tanks, the submarine can submerge or surface.

sinks to lower levels. By changing the size of its swim bladder, a fish can float at whatever level it chooses.

A submarine cannot change its size as a fish can, but the submarine can make use of

**How does a submarine move up and down in the water?**

Archimedes' Principle in another way, so as to change the level at which it floats. Inside a submarine, there are large tanks into which sea water can be pumped. When the tanks are empty, the submarine floats at the surface of the sea. This means, of course, that the weight of water the submarine displaces is the same as the weight of the submarine, and therefore the buoyant force acting on the submarine is equal to the submarine's weight.

When a submarine commander wishes to take his craft beneath the surface of the sea, he pumps water into the tanks within the submarine. As the tanks fill, the weight of the submarine becomes greater than the weight of the water it displaces; the buoyant force acting on the submarine becomes less, and the craft sinks. By varying the amount of water in the tanks, the sub-

marine commander can choose the level at which the submarine will float.

Once a boy took a heavy earthenware jug to a well. He filled the jug until it overflowed. Then

**What is Pascal's Principle?**

he put the stopper into the mouth of the jug and, to make sure that the stopper would not fall out, he struck it sharply with the palm of his hand. He was astonished when the whole bottom fell out of the jug! Why did the jug break when its stopper was struck a blow that would not ordinarily be strong enough to break a jug made of heavy earthenware? In order to understand what happened, we will have to learn something concerning liquids that was discovered by a young French physicist, mathematician, and philosopher named Blaise Pascal, who lived some 300 years ago.

What Pascal learned was this: if you apply pressure anywhere to a fluid held in a container, the pressure will pass through the fluid in every direction without any loss of strength. This discovery is known as Pascal's Principle.

Suppose we have a big iron tank in the shape of a cylinder. It is lying on its side and is six feet high and ten feet long. The tank is filled with water. A small piston is fitted into one end of the



tank and a large piston into the other end. The pistons are square, and the small one has a surface just one inch across, while the large one has a surface ten inches across. A square that is one inch across has an area of one square inch; a square that is ten inches across has a surface area of 100 square inches.

Now suppose a man pushes on the small piston. How many men will be needed to push against the big piston in order to keep it from being pushed outward at its end of the tank? A hundred men! The water transmits to each of the 100 square inches on the surface of the big piston the same amount of pressure that was applied to the one square inch of the small piston. If the man pushed on the one-inch-square piston with a pressure of 60 pounds, that 60 pounds of pressure would have passed through the water to every other square inch in the tank. The large piston had 100 square inches, so 60 pounds of pressure passed through the water to each one of the 100 square inches of the large piston. One hundred times 60 is 6,000, so 6,000 pounds of pressure was pushing against the large piston. No wonder it would take 100 men to hold the large piston against the pressure exerted by one man.

Now you can understand why the earthenware jug broke. Suppose the stopper had a bottom surface of one square inch. Let us say that the bottom of the jug had an area of 80 square inches. Also, let us say that the boy hit the stopper with a pressure of 20 pounds. If a pressure of 20 pounds passed through the water to every one of the 80 square inches of the jug's bot-

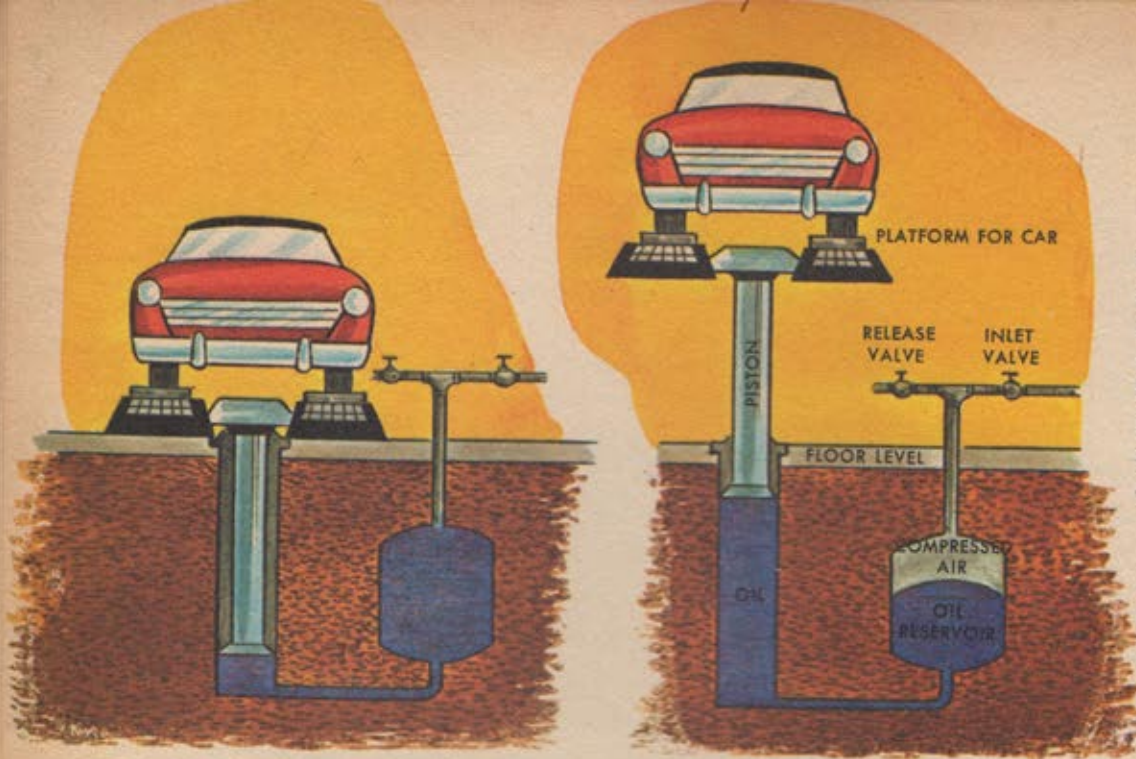
tom, then 1,600 pounds of force suddenly pushed on the bottom. No wonder the jug broke!

Have you ever seen a man fix a flat tire on the wheel of  
**How does a hydraulic jack work?** of a big truck or trailer?

First, he had to lift the wheel off the ground. To do this he used a tool called a jack. He placed the upright part of the jack under a part of the truck's frame; then he pumped a handle up and down; as a result, the upright part of the jack moved slowly upward, pushing the truck's heavy frame with it. The jack that is needed to lift an object as heavy as a truck is a *hydraulic* jack. "Hydraulic" means "operated by water." Inside the jack is a thick iron cylinder filled with water. Every time the man pushed the handle down, a small piston pushed against the water in the cylinder, and the push passed through the water to a large piston, where the strength of the push was so greatly increased that the heavy truck could be lifted upward.

Many machines have been constructed to multiply force by means of Pascal's Principle. One of these is the hydraulic press that is used to bale cotton. You know that cotton is very light and fluffy. It would be very awkward to ship large amounts of cotton just as it comes from the cotton plant; the fluffy cotton would take up so much room. So, cotton is placed in large burlap sacks and compressed by a hydraulic press. When the baler pushes a small piston, a large one is moved upward, squeezing air out of the cotton by push-





The way in which the jack works to hoist automobiles in a service station, is based on Pascal's Law. Today oil is used instead of water in many hydraulic appliances.

ing the sack against a flat square of iron. Wires are wrapped around the compressed cotton to keep it from fluff-

ing out again. The hydraulic lift that raises cars above the ground in service stations also uses Pascal's Principle.

## Air, Water, and You

You have learned that air and water are very important substances. Without them, there would be no life at

**How can you help keep air and water clean?**

all. Sometimes air and water become *polluted*, that is, they become dirty and even dangerous to use. When this happens, man has to find a way of making them clean and safe again. Perhaps you have seen a polluted pond or stream from which no one is allowed to drink water or swim in because he would get sick if he did. In some cities the air, too, becomes very dirty. Sometimes it gets so dirty that people cough and choke and their eyes water.

As the population of our country increases, more and more waste materials will be emptied into the air and into

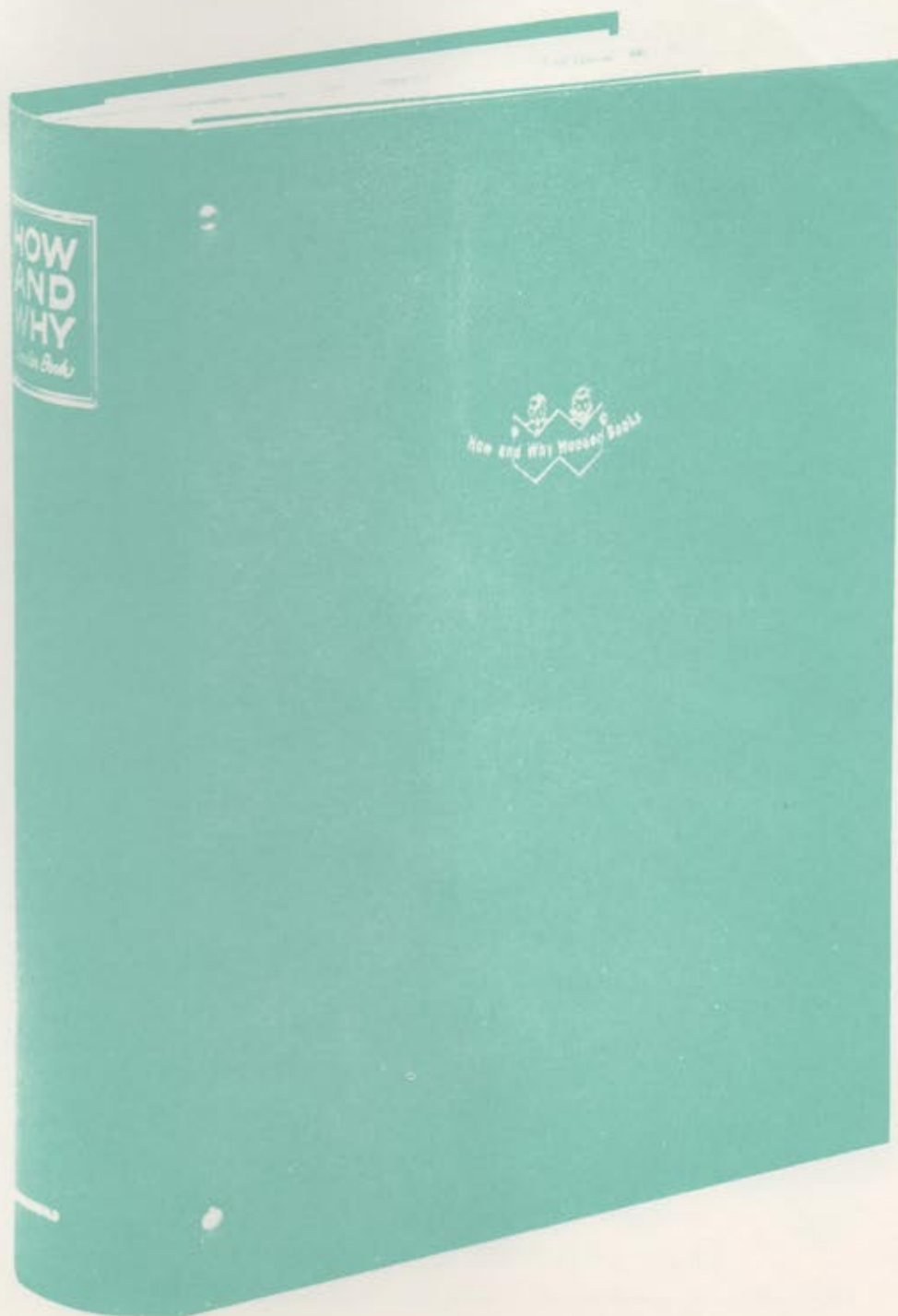
lakes and rivers. Many people are needed to work at keeping our air and water clean. We need engineers to build dams and sewage systems. Chemists are needed to test water and air to see if they are safe, and researchers are needed to discover new ways to make them clean. People are needed to advise farmers on the best way to plant crops so that soil erosion will be prevented. We need other people to plan cities and towns so the factories and dumps that might pollute the air and water are not built near homes.

These tasks offer much interesting work that can be a rewarding lifelong career. Perhaps you will one day enter one of these useful and challenging fields working to keep our air and water clean and safe.



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